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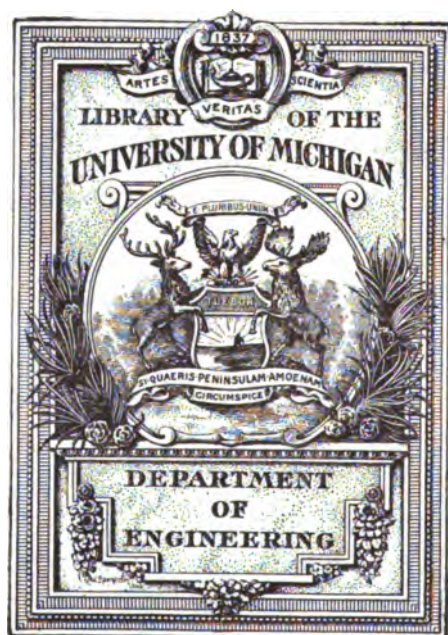
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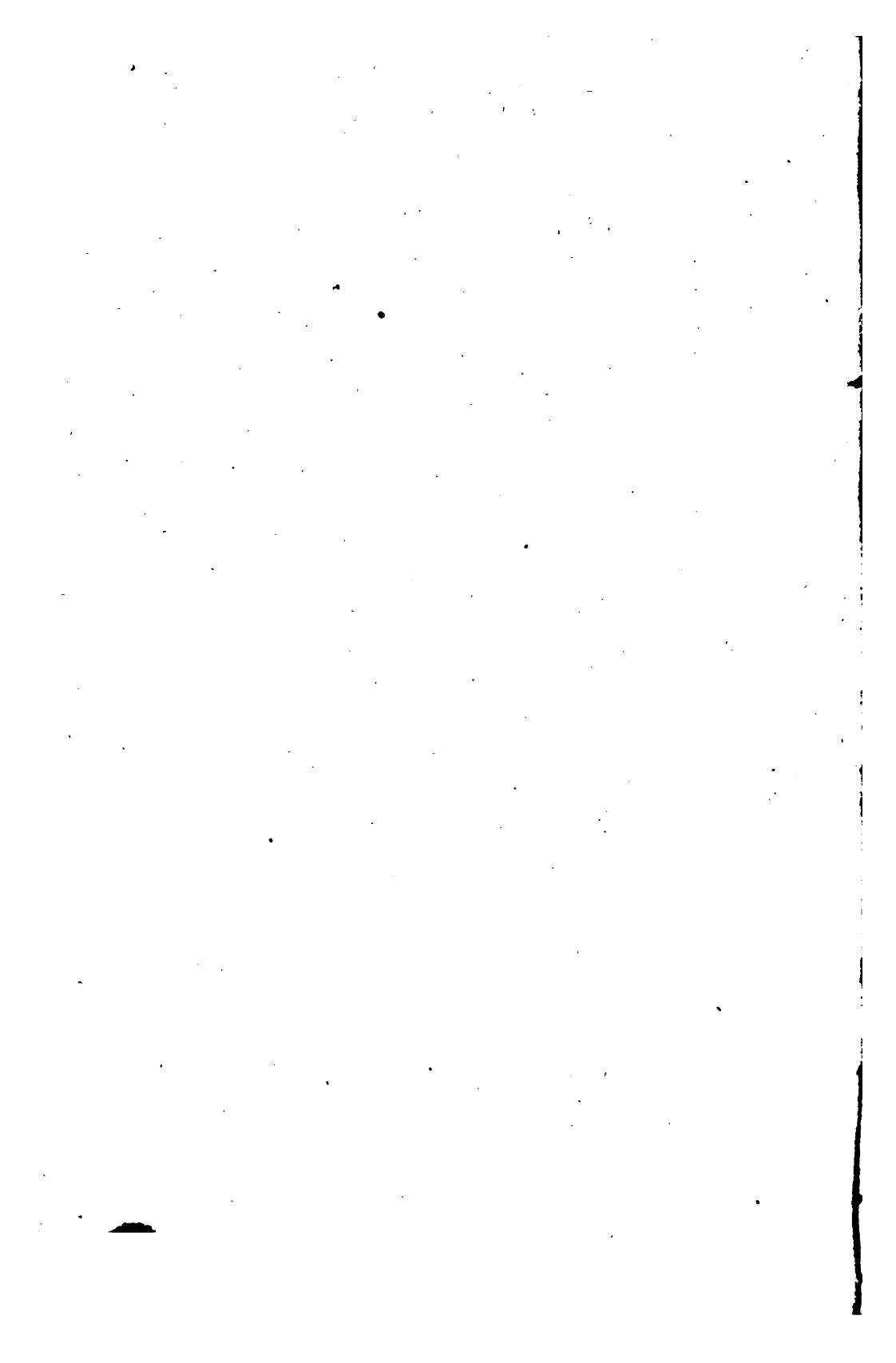
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1874



HANDBOOK OF PRACTICAL TELEGRAPHY.

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A HANDBOOK
OF
PRACTICAL TELEGRAPHY.

Revised by
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*ADOPTED BY THE POST OFFICE AND BY THE DEPARTMENT OF
TELEGRAPHS FOR INDIA.*

SIXTH EDITION, REVISED AND ENLARGED.

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PREFACE TO THE FIFTH EDITION.

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THE intention of the Author has been to give information to members of the Telegraph Service, and to those interested in Telegraphy, concerning—

The Electrical Laws upon which the system depends :

The Methods of discovering Faults :

The Practical Management of Apparatus :

The Construction of a Line :

And the Leading Principles of Submarine Telegraphy.

He has attempted to supply in some measure that technical knowledge which has hitherto been attainable only by means of verbal instruction or actual experience ; and, with a view of rendering the work more acceptable to practical men, he has purposely avoided scientific terms and formulæ, especially in the earlier portion of the work, and elsewhere, when it has been possible to express his meaning without their use.

The Author thanks his friend Mr. Preece for his valuable help, and expresses his obligation to those

members of his Staff who have so kindly and effectively assisted him.

He must also thank Mr. Chatterton, Mr. Willoughby-Smith, Mr. Latimer Clark, Mr. Forde, Mr. Hockin, Mr. Warren, Mr. Fleeming Jenkin, Mr. Varley, and Sir C. Wheatstone, for the information they have so courteously supplied.

LONDON, *May* 1874.

SIXTH EDITION.

THE Author has re-written many portions of the present Edition, and has given a description and drawings of the latest form of Wheatstone's automatic apparatus. He has added a chapter on the Duplex System, in which he was greatly assisted by his valued friend Mr. Stearns; to whom he begs to return his sincere thanks, as also to Mr. Sabine for his contribution on strains in suspended wires.

January 1874.

INTRODUCTION.

As the Telegraphs in Great Britain and Ireland have now passed into the hands of the State, a slight sketch of the history of the system in this country may not be out of place.

The Electric Telegraph was introduced by Cooke and Wheatstone, whose first joint patent was granted in 1837, in which year the earliest demonstration of the practicability of the system was made by the establishment of an experimental circuit between Euston and Camden Town, on the London and Birmingham Railway.

The first actual working telegraph was erected in 1838, between Paddington and West Drayton, on the Great Western Railway.

Cooke and Wheatstone's patents were purchased by the Electric and International Company, of which

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Mr. John Lewis Ricardo was chairman ; and in 1846 the Company was incorporated by Act of Parliament.

No assistance whatever was granted by the Government ; and it was only after several years of adversity that the undertaking became firmly established.

In the first instance, the double needle instrument was used for the more important circuits, the single needle for the less important. The double needle was superseded, after a few years, by the chemical recording instrument of Alexander Bain ; and eventually the Bain gave way to the Morse ink-writer, but the single needle held its place in consequence of the great ease with which it is kept in working order. Between London and Manchester, Glasgow, Edinburgh, and Newcastle, the Wheatstone automatic apparatus was used.

When the success of the telegraph had become established, other companies started.

The " Magnetic " Company was formed to introduce Henley's needle instrument, in which the electricity was obtained from a permanent magnet instead of from a battery, but the manipulation of the magnet was found

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to be too laborious, and it was abandoned for the battery. This needle instrument was superseded, for important circuits, by Bright's Bell, which produces the signals of the single needle code by strokes upon two bells of different pitch, and has the great advantage over the needle that it leaves the hands free for writing the message as it is received.

Lastly, the "United Kingdom" Company was formed. This Company used the Morse and Hughes only, and never employed the needle instrument.

Several of the railway companies transmitted messages for the public.

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It is not necessary, however, in a practical handbook, to discuss questions which are simply hypothetical, nor to enter into those parts of electrical science which have not an immediate bearing on telegraphy.

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2. If two narrow strips of very thin gutta-percha be laid side by side, and drawn quickly between the fingers, they will *repel* each other, but the excited glass tube will *attract* them. If a sheet of well-dried and warmed paper be vigorously rubbed with india-rubber and quickly cut into strips, the strips will repel one another when lifted from the table.

Upon this principle the *electroscope* (Fig. 1), an instrument for showing the presence of electricity, is made.



FIG. 1.

Gum two strips of gold leaf to the opposite sides of a thin piece of card; fix the card on a wire, taking care that the wire touches both the gold leaves; let it pass through a plug of sealing-wax or ebonite fixed in a hole in a glass shade (a glass-flower-pot answers very well); screw a brass knob upon the wire, and place the glass shade on a stand. Or suspend two balls of elder pith by dried sewing silk from suitable supports, so that they may hang side by side, a little apart. Elder-pith balls are used instead of gold leaf because they are not liable to be disturbed by currents of air.

3. Touch the knob of the gold-leaf electroscope with the *excited glass*, the leaves will diverge; they repel each other, in the same manner as the strips of gutta-percha.

Touch both the pith balls with the glass, they also repel:

touch both with the finger, the repulsion ceases; touch both with the ebonite or sealing-wax, they again diverge: but touch one with the glass, the other with the ebonite or wax, they *attract* one another. They will also attract one another when only one of them is electrified.

4. It appears, then, that the condition or state of electrical excitation produced by rubbing glass, differs from that produced by rubbing ebonite or sealing-wax. The first is called "*positive*" or "*plus*," and is designated by the sign $+$; the second "*negative*" or "*minus*," and is designated by the sign $-$. These terms are entirely arbitrary; all that is meant by them is that the two states are *opposed* to each other, but not that there is more electricity in the one than in the other.

Bodies similarly electrified are said to have the *same sign*, if dissimilarly electrified they are said to have *opposite signs*.

5. *Bodies similarly electrified, both $+$, or both $-$, repel. Those dissimilarly electrified, one $+$, the other $-$, attract.*

In order, then, to ascertain the *sign* of an electrified body, it appears only necessary to find whether it is attracted or repelled by an excited body whose *sign* is known. But as attraction occurs even when only one of the two bodies is electrified, it is better to find by trial which electricity will cause *repulsion*.

6. The two opposite states are always produced at the same time, and in exactly the same proportion—that is to say, when two substances are rubbed together they become oppositely or dissimilarly electrified, and to an equal degree; they therefore always attract one another. Thus, when ebonite is rubbed with cloth, the former becomes $-$, the latter $+$; when glass is rubbed with cloth, the glass becomes $+$ and the cloth $-$; but when glass is rubbed with cat's fur it becomes $-$, and the fur $+$. Glass, then, when rubbed, does not always produce $+$ electricity, nor, it may be, ebonite always $-$.

7. When the leaves of the gold-leaf electroscope are divergent, if the ball is touched with a body *similarly* but more strongly electrified the divergence will *increase*. But if the body is *dissimilarly* electrified, the divergence will *decrease*. If the quantity of the opposite electricities in the two is exactly equal, they will *neutralize* each other, and all signs of electricity will disappear.

The same effect will be produced if the ball is touched with the finger.

8. A metal rod held in the hand and rubbed, will exhibit no sign of electricity; it will neither attract nor repel; nor will the cloth with which the ebonite or glass was rubbed, unless proper precaution be taken in each case.

9. *Some substances, such as metals and cloth, have the property of allowing electricity to diffuse itself freely throughout their whole mass, and are hence termed conductors.*

Others, such as glass and ebonite, offer very great resistance or opposition to this diffusion, and are called non-conductors, or insulators.

When a conductor is fixed upon or supported by a non-conductor, it is said to be insulated.

10. When the metal rod or the cloth is held in the hand and rubbed, the electricity produced by the friction immediately diffuses itself over its surface and the surface of the rubber, through the body of the experimenter; so that the opposite conditions immediately neutralize one another, and the equilibrium or balance of electricity is restored without the exhibition of electrical phenomena: for metals, cloth, and the human body are *conductors*.

On the contrary, when the glass or ebonite is rubbed, the electricity does not diffuse itself or become neutralized, but remains where it was produced, manifesting its presence by causing attraction or repulsion; glass and ebonite being *non-conductors*.

But if the metal rod be *insulated* by being fixed on a glass handle, and then rubbed, it repels or attracts; for now the electricity cannot escape, being confined to the rod by the insulating handle. In like manner, if the cloth be insulated by being held in a sheet of india-rubber, its electricity will manifest itself.

11. In order to deprive a non-conductor of the electricity excited on its surface, we must touch every part of it with the hand, or some other conductor. Whereas, a conductor can be deprived of its charge by touching one point of its surface only.

12. The division of substances into conductors and insulators is not absolute. There are few (if any) bodies which are perfect

insulators, or which do not conduct *at all* under any circumstances; while even metals, the most perfect of all conductors, offer a certain *resistance* to the passage of electricity, or, in other words, insulate slightly. The terms imply a difference in degree only—good insulators are bad conductors, and good conductors bad insulators.

Each of the substances in the following table conducts better than that which precedes it; the first on the list is the best insulator, the last is the best conductor.

Dry air.	Wool.	Acids.
Ebonite.	Dry paper.	Charcoal or coke.
Paraffin.	Porcelain.	¹ Mercury.
Shellac.	Dry wood.	Lead.
India-rubber.	Dry ice.	Tin.
Gutta-percha.	Stone.	Iron.
Resin.	Pure water.	Platinum.
Sulphur.	Melting ice.	Zinc.
Sealing-wax.	Rarefied air.	Gold.
Glass.	Sea water.	Copper.
Silk.	Saline solution.	Silver.

Some descriptions of glass, if artificially dried, insulate better than gutta-percha.

13. The electrical machine is the most convenient apparatus for developing electricity by friction. It consists of a cylinder or plate of glass—or better, of ebonite—fixed upon an axis, and having *rubbers*, or cushions of leather stuffed with horsehair, so arranged as to press upon the glass and rub it when the axis is turned. An insulated metallic rod, or cylinder, collects the electricity from the glass, and is called the *prime conductor*.

Ebonite is better than glass, because it is less liable to break, and is less affected by damp. An ebonite machine must be very carefully protected from dust.

14. When an electrical machine of glass with an insulated rubber is set in motion, the rubber becomes negative, the glass positive, and they may be called the negative and positive *poles*

¹ The order of conductivity is that of pure Metals, according to Matthiessen's most recent determinations. (Miller's Chemical Physics, 1867.)

of the machine. The glass communicates its positive electricity to the conductor, which then becomes the positive pole, and a pair of pith balls suspended from it, having the *same sign* will *repel* each other, while a ball suspended from the conductor will *attract* one suspended from the rubber, because they have *opposite signs*.

The force with which the pair of balls hung from the conductor are repelled is proportional to the *difference of potential* between the conductor and the earth, and the force with which the other pair attract one another is proportional to the difference of potential between the conductor and the rubber. Their divergence is, roughly, a measure of this difference of electric condition.

When ebonite is used instead of glass, the rubber becomes positive and the plate negative.

14a. The term *potential* is applied to electricity in the same way that the word pressure is used with reference to a fluid.

Difference of potential determines the passage of electricity from one point to another, in the same way that difference of pressure gives water or air the power to flow from the point of higher pressure to that of lower pressure, enabling it to overcome resistance and perform work. It must not be understood by this that electric force has in itself any resemblance to gravity or mechanical pressure.

The potential of the earth is the zero of electric condition, as the level of the sea is the zero or datum line from which heights are measured. In this sense positively electrified bodies are at a higher potential than the earth, and consequently when such bodies are placed in connection with the earth electricity flows from them to the earth; in the same way negatively electrified bodies are at a lower potential than the earth, and when they are placed in connection with the earth electricity is transferred from the earth to them. The terms higher and lower are, however, purely conventional: they merely denote opposite states or conditions.

So long as the rubber and conductor remain insulated, the continued friction increases the difference of their potentials, making the one more negative, the other more positive, until

the difference at last becomes so great as to cause a spark to pass between the two, restoring electric equilibrium. This is called an electric *discharge*.

15. If the rubber and conductor are connected by a wire, no electrical effects are observed, because the two opposite conditions are instantly neutralized as soon as formed, and no difference of potential is maintained. But if the wire be reduced in diameter and increased in length, so as to become extremely long and very thin, its conducting power will be so much decreased, that a difference of potential will be maintained and the neutralization will proceed gradually by the passage of a *current* of positive electricity from the conductor to the rubber. A few feet of wet string may be used instead of the long fine wire.

Before the discharge takes place or the current commences to flow, the electricity is said to be in the *static*¹ condition; during the discharge it is in the *dynamic*¹ condition, because it then exercises force or performs work.

16. *Whenever there exists a difference of or potential between two points connected by a conductor, a current passes between them until equilibrium is established.* The term *current* does not, however, imply the actual passage of any fluid or gas, but a simple transfer of force, an action which is progressive in its nature, like the passage of light through space, or of heat through a bar of metal. This action will be better understood further on, when *induction* has been studied.

17. There are many other methods of producing electricity, of which chemical action is the most important.

Electricity produced by chemical action is called *galvanic* or *voltaic*, from the names of its discoverers, Galvani and Volta. The apparatus for producing it is called a voltaic *pair* or *cell*, and consists of a pair of conducting plates immersed in a liquid which acts, chemically, more upon one than upon the other. When several cells are connected together, the arrangement is called a *battery*.

Zinc is universally employed as one of the pair, and the

¹ The words *static* and *dynamic* are derived from the Greek : the one conveys the idea of *rest*, the other that of the *power* due to *motion*.

greatest effect is obtained when the second plate of the pair is not acted upon at all by the liquid employed, for as the difference of potential between the two plates of the pair is proportional to the difference of the chemical action upon them, if it were possible for both metals to be attacked equally, there would be no difference of potential between them, and consequently there would be no tendency towards a transfer of electricity; but if the chemical action be greater upon one than upon the other, the potential of the two will differ by an amount equal to the difference of chemical action; and as this difference increases so will the difference of potential increase. Therefore, when there is *no action* upon the second plate, the difference of potential is the greatest possible.

18. As voltaic electricity is produced whenever the conditions just mentioned are complied with, there are many different methods of making a battery. The *specific power* which each combination possesses of producing a difference of potential, giving the power of causing a transfer of electricity from one place to another, it is called its *electromotive force*. This term, strictly, means *any cause whatever by which difference of potential is produced between any two points*.

19. In dilute sulphuric or nitric acid, the substances furthest apart in the following list form the most energetic combination.

¹ Graphite	Iron.
Platinum.	Lead.
Silver.	Tin.
Copper.	Zinc.

20. But as the power of maintaining an electric current depends on the difference of the chemical action upon the two plates, it will be altered by a change in the liquids employed: for instance, iron stands below copper when sulphuric acid or solution of common salt is used, while in ammonia the order is reversed.

21. So long as the two plates are not connected by a conductor exterior to the liquid, the electricity produced remains in

¹ Carbon from gas retorts.

the *static* condition, and, like frictional electricity, may be made to produce attraction and repulsion, so as to cause the gold leaves of an electroscope to diverge. But the tension of voltaic electricity is feeble, so that unless a considerable number of cells are used a *condensing* electroscope (152) is necessary to produce the effect. The electroscope of Professor Sir W. Thomson is, however, sufficiently delicate to show attraction and repulsion where the electro-motive force is as feeble even as one-tenth of of a Daniell cell, and that without the aid of a condenser.

22. When the plates are connected by a wire, or other conductor, the opposite electrical conditions neutralize one another (10). But they are instantly restored by the chemical action, and are again as quickly destroyed. Thus a constant transfer or *current* is established, and the electricity is said to be in the *dynamic* state. It will still affect the electroscope, but has gained the power of deflecting a magnetized needle.

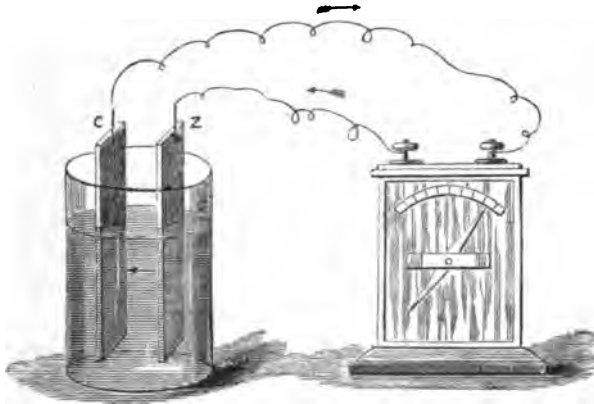


FIG. 2.

23. The + electricity is supposed to set out from the more oxidizable metal, called the *positive* or *generating* plate, because it furnishes the supply of electricity; to pass through the fluid to the less oxidizable metal, called the *negative* or *collecting* plate, because it collects the electricity from the liquid; and thence by the connecting wire to the zinc again. But the *end of a battery* containing the *generating plate* (generally zinc) is called

the *negative pole*, because it is there that the negative electricity is accumulated (the positive having passed into the liquid); while for a similar reason the last *collecting plate* is called the *positive pole*, since by it the positive electricity leaves the battery.

When zinc and copper are formed into a battery, the positive electricity passes from the zinc through the liquid to the copper, and from the copper by the conducting wire attached to it back to the zinc again. (See Fig. 2.)

24. When two or more pairs of plates are so connected that the positive metal of the first is united by a metallic conductor to the negative metal of the second, and so on, the tension is increased in direct proportion to the number of pairs. Four pairs will have four times the tension of one pair, will produce a current capable of overcoming four times the resistance, and will cause the electroscope to diverge four times as much.

25. Let the electromotive force of a copper and zinc pair in dilute sulphuric acid be such as to cause a difference of potential of (say) 10 between its two plates.

If either pole be connected with the earth, its potential will become that of the earth, that is, will fall to zero. But as the electromotive force of the pair has the power of producing a difference of potential equal to 10, the insulated pole will, if it be the positive, have a potential of 10 above, and if the negative of 10 below that of the earth. Let the zinc be connected to earth.

The copper will have a potential 10 above that of the earth, and if it be connected to the zinc of a second similar pair, it will communicate to it its potential.

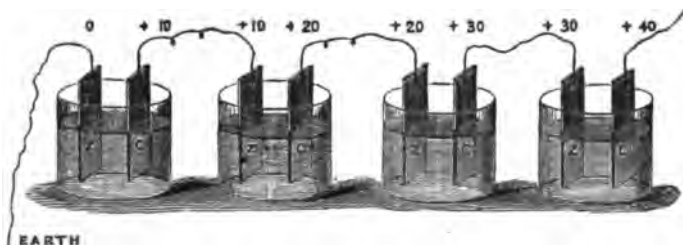


FIG. 3.

But as the difference between the plates of the second pair is also 10, and the second zinc has already a potential of 10, the

potential of the second copper will be $10 + 10 = 20$, and so on, so that the difference between its *poles* or end plates will be four times ten, or forty.

If *both* poles be *insulated*, the centre plates will be neutral : the zinc pole will have a potential of 20 *below*, and the copper pole a potential of 20 *above* the potential of the earth, the difference between the two being 40, as before.

26. Though the difference of potential increases with every additional pair, no greater *quantity* of electricity will be produced with even a thousand pairs than with one pair ; for the action in each cell is simply to urge forward a quantity equal to that arising from the oxidization or solution of the zinc of the first pair, and not to produce more electricity.

27. But if all the four zincs are joined together, and all the four coppers are similarly connected, so as to form, as it were, a pair of four times the surface, the *quantity* will be fourfold, but the difference of potential will remain the same as with one pair of the original size. There will be four times *more* electricity produced, but its power of overcoming resistance will be the same as that of one small pair, and the difference of the potential of its poles will be but ten. This subject is treated more fully in the chapter on the laws of the current.

28. As the number of cells is increased, the effects of the battery approach more and more closely to those of the frictional (or electrical) machine, until, with 500 cells well insulated, attraction and repulsion may readily be shown without the aid of the condenser (152). By still further increasing the number, and carefully insulating them, the difference of potential may be so far increased as to overcome the resistance of the air, and to produce a spark when the conducting wires are separated.

29. The electricities produced by the machine and the battery are in fact identical, the difference between them being only this : the electricity of the former is of high potential, but the *quantity* generated is so small that it is with difficulty a current can be made manifest, even with the arrangement described in paragraph 15, while in the latter the potential¹ is comparatively

¹ When the word potential is used alone, it means the difference of potential between the body or point and that of the earth.

low, but the quantity is abundant enough, even from a very small pair of plates, to keep up a sensible current even through a good conductor. The lowness of the potential of voltaic electricity renders the insulation of the conducting wire comparatively easy, while frictional electricity, from its great power of overcoming resistance, passes by even the most imperfect conductors. Hence the earlier attempts in electric telegraphy, in which the machine was used, were failures, because the conducting wires could not be sufficiently insulated.

30. Faraday has calculated that a wire of platinum and one of zinc $\frac{1}{16}$ th of an inch thick, immersed $\frac{1}{8}$ ths of an inch in a mixture of one drop of acid to four ounces of water, will produce in three seconds as great a quantity of electricity as thirty turns of a 50-inch plate machine. Voltaic electricity has been compared to steam rising quietly from an open boiler, while frictional electricity is the high-pressure steam of a locomotive. Lightning is the spark or discharge of electricity of very high potential.

31. Although chemical action is the cause of electromotive force, such action may take place in the cells of the battery without adding to the strength of the current, for if a small piece of iron or copper, for instance, touches the zinc plate, voltaic action will be set up between them; while the neutralization of the potential will take place upon the surface of the metal instead of through the connecting wire, so that the zinc is wasted. This is called *local action*, and the greatest care must be taken to prevent it.

32. When copper, *pure*, zinc, and dilute sulphuric acid are formed into a battery, there is no action so long as the poles are disconnected; but if ordinary zinc is used, bubbles of hydrogen are given off from its surface immediately it is placed in the acid, even if there be no copper plate in the liquid. The evolution of hydrogen arises from the *local action* caused by the particles of lead, carbon, iron, and other impurities contained in the metal, which being negative to zinc form small batteries on the surface of the plate, dissolving it away in holes without producing any useful effect. When old zinc plates are recast, the impurity of the metal is increased, for, besides the foreign

matters it originally contained, there will be found particles of copper which have been deposited on the plates while in action. The metal at the bottom of the crucible will be the most impure.

33. Pure zinc is very rare and expensive, and therefore cannot be used; but by the process of *amalgamation* common zinc is rendered equally serviceable. The simplest way to amalgamate zinc is to clean it by dipping it into dilute sulphuric acid; then place the plate in a shallow dish containing a little dilute sulphuric acid, and pour a small quantity of mercury upon it, rubbing the mercury over the surface with a piece of rag tied round the end of a stick, keeping the rag well wetted with the acid. A small strip of zinc is sometimes useful to collect the mercury from the dish and place it on the plate. The mercury dissolves a little zinc, which flows over and covers the foreign particles, preventing their contact with the acid.

34. When the poles of a battery are united by a conductor, a current is established, the water in the cells is decomposed, or separated into its component gases; the oxygen is set free at the zinc plate and combines with it, forming zinc oxide, which the acid immediately dissolves, converting it into sulphate.

The hydrogen is set free at the copper plate, and escapes in bubbles; but hydrogen in this particular condition, called its *nascent state*, has the power of separating metals from their solutions, so that as soon as the zinc sulphate dissolved in the water has so far diffused itself through the liquid as to reach the copper plate, it is decomposed by the hydrogen, coating the copper plate with zinc. This action tends to convert the battery into one in which zinc is eventually opposed to zinc, and therefore reduces, and finally destroys, its force.

Again, a portion of the hydrogen adheres to the copper, acting upon it as if it were a liquid (20). But as copper excited by hydrogen takes up a potential opposite to that of copper excited by sulphuric acid in the presence of zinc, the power of the battery is lessened. The copper plate is said to have become *polarized*.¹

¹ The term "polarized" is here used in a sense somewhat different from that which it bears on the first page.

35. To render a battery *constant*—that is, uniform and lasting in its action—polarization and deposit of positive metal upon the negative plate must be prevented. This is best effected by surrounding the negative plate by a strong solution of a salt of the metal itself, because then the hydrogen will not escape or cover the plate, but will be solely employed in reducing metal from its solution; and as the reduced metal is the same as that of which the plate itself is composed, the battery, instead of losing, will gain, because the negative plate will be kept constantly clean and bright by the new metal deposit upon it.

36. The *Daniell Battery*, in great measure, fulfils these conditions. It consists of a cell or jar containing a cylinder of amalgamated zinc, and a cell of porous earthenware, smaller than the zinc cylinder and fitting inside it. The *porous cell*, as it is technically called, contains a plate or cylinder of copper, and is filled with a solution of copper sulphate, while the outer jar is filled with dilute sulphuric acid. So long as the zinc and the copper are not connected by a conductor there is no chemical action, for the acid does not act on amalgamated or on pure zinc (33), nor the copper sulphate on the copper; but the moment the circuit is closed—that is, as soon as a communication is established between the two metals—the zinc is strongly attacked, but no hydrogen is given off at its surface, as there is no local action. Water is decomposed, zinc oxide is formed, which the acid dissolves, forming zinc sulphate. The hydrogen passes to the copper, but instead of escaping at its surface, adhering to it and *polarizing* it (34), it decomposes a portion of the copper sulphate precipitating copper upon the copper plate, keeping it clean and bright.

The acid of the copper sulphate passes to the zinc, assisting the sulphuric acid already there to dissolve it and form zinc sulphate. The only use of the acid originally placed in the zinc cell is to make the fluid round the zinc a better conductor; and when a large quantity of electricity is required, the copper sulphate is also acidulated with half its bulk of strong sulphuric acid. The action of the battery is therefore to form zinc sulphate in the zinc cell, and to consume copper sulphate in the

copper cell, the zinc being constantly dissolved away while the copper plate is increased.

When the action of the battery has decomposed all the copper sulphate, the action ceases; and if any zinc sulphate has passed into the copper cell, as will generally be the case, zinc will be reduced upon the copper plate as a black powder. It is necessary, therefore, to provide a constant supply of copper sulphate, which should be placed at the bottom of the cell for long-continued action, but at the upper part of the cell when energetic action is required, as it then dissolves more regularly and quickly.

37. When the acid in the zinc cell becomes saturated with zinc, the battery, though less powerful, will be more constant than when excited by acid.

A solution of zinc sulphate may therefore be used in the zinc cell in place of sulphuric acid, and it will not then be necessary to amalgamate the zinc plate, as there will be little or no local action (32).

When continued action is required, mercury is positively injurious, because the metallic copper which is deposited on the zinc plate (41) forms an amalgam with the mercury, which very greatly impedes the action of the battery, far more so than when deposited on unamalgamated zinc.

38. Should the water become saturated with zinc sulphate (i.e. contain as much as it can dissolve), the sulphate crystallizes upon the zinc plate, stopping the action of the battery. The conducting power of a solution of zinc sulphate is greatest when diluted with an equal quantity of water. Part of the solution should, therefore, be from time to time removed and replaced by water (82).

39. If the porous cell be of bad quality, containing coke or metal dust, the copper will be deposited in patches upon it. When these patches of copper touch the zinc, they form local circuits, like the particles of foreign matter contained in the zinc itself (32), wasting both copper and zinc sulphates. When the porous cell becomes crusted with copper, it should be removed.

40. The zinc should never be allowed to touch the porous cell, for copper will immediately be deposited on the porous material, and thus form a local circuit with the zinc.

41. Porous cells but very imperfectly prevent the mixing of the liquids. The liquid passes through the porous cell from the zinc to the copper in virtue of a singular property common to all porous substances when dividing dissimilar liquids, called "osmose," and it will frequently rise in the copper cell an inch or more above the level. The current aids this movement. The copper solution passes into the zinc cell, and is decomposed by the zinc plate. The sulphuric acid of the copper sulphate leaves the copper, dissolves the zinc, for which it has a greater chemical *affinity*, and copper is deposited, in a metallic form or as a black spongy mass, upon the zinc plate, or falls to the bottom of the cell. When the cells are very porous, as much zinc is dissolved and copper sulphate used when the battery is idle as when it is at work. The zinc plates should be frequently scraped to remove the deposit, which is very valuable, and should be carefully preserved.

42. The chemical action of zinc upon copper sulphate is well shown by suspending a piece of the metal in a weak solution of the salt: the zinc will be covered with metallic copper in a few minutes, and in a short time the whole of the copper will be removed from the solution and replaced by zinc. By this means the copper contained in the waste zinc solution may be removed, and the liquid fitted for charging fresh troughs.

43. The zinc cell should be much larger than that containing the copper, in order that the copper sulphate which leaks through may have more liquid into which to diffuse itself, and thus become more dilute; the zinc will then act on it less rapidly. The copper cell should be a little taller than the zinc, so that it may not overflow. The porous cells of a battery intended only for occasional use should be somewhat thicker than those of one constantly in action; for the loss of power due to the extra thickness of the porous material (83) is more than compensated by the diminished waste of copper sulphate, caused by the obstacle which the thicker cell presents to the mixing of the solutions. If a separate porous cell is used, its back, sides, top, and bottom should be dipped in good hard melted tallow or paraffin, to prevent the solution passing through those parts that do not face the zinc.

44. If the several cells of a trough leak into each other, the action of the cells will be increased, but the effective current will be reduced by the formation of "short circuits." The same happens in some measure when the sides of a trough are wet, or encrusted with salts.

45. A defective cell, arising from a leakage or a broken porous partition, is sometimes found, reducing the power of the whole battery. In such a case it is a good plan to bridge it over thus:—Thoroughly clean the straps of the two battery plates between which the defect lies, and connect them across by a piece of wire.

46. When the water has become saturated with the zinc sulphate produced by the action of the battery, crystals form on the sides of the cell; the liquid passes up between them and the sides, crystallizing again above, until at last the crystals pass over the edge, and form a kind of syphon, which draws off the liquid, especially when the trough is made of gutta-percha, which is an unsuitable material for the purpose. This may, in great measure, be prevented by painting the edge of the cells with solid paraffin, dissolved in warm paraffin oil. Porcelain cells may be dipped in the mixture about half an inch, after having been well dried. The crystals should be occasionally removed with a damp cloth.

47. In consequence of the tendency of the solutions to mix through the porous cell, a battery has been contrived in which the solutions are separated by their respective weights alone. The copper solution being heavier than the zinc, the copper plate and crystals of copper sulphate are placed at the bottom, the zinc plate being hung perpendicularly near the top of the cell, which is filled with a dilute solution of zinc sulphate.

In this battery, called the "gravity" battery, the cells should not be quite filled with crystals, for when the level of the copper solution is raised to the zinc plate, the zinc reduces the copper from the solution. It is a very common and a very wasteful process to put in as much sulphate as the cell will hold.

When the plates are placed vertically, the two metals should never face or cross each other, but the upper edge of the copper should be level with, or rather below, the lower edge of the zinc

If the zinc be below the upper edge of the copper, it will remove all the metal from the copper sulphate solution as far as the zinc plate reaches, and it will therefore leave none to act upon that part of the copper plate which faces the zinc. The copper sulphate should be so placed as to dissolve only just as fast as it is used up by the action of the battery, for although its solution is heavier than the solution of zinc in the upper part of the vessel, the two will certainly mix after a few days, in accordance with the laws of the diffusion of liquids.

This battery has been very extensively used, but the extra care required in managing it more than counterbalances its advantages; absolute rest is essential to its constancy and durability.

48. For common use, the following is a good and economical battery. It is a modified Daniell. A teak trough, with a lid, is divided into cells by plates of glass or slate, and well coated with marine glue. The cells are subdivided by a slab of porous porcelain, $\frac{1}{4}$ -inch thick. The plates are cast zinc, 4 inches $\times$ 2 inches, and thin copper 4 inches square. A copper strap is cast into the zinc and riveted to the copper plate: the end which is cast into the zinc is previously tinned, to ensure contact. The zinc hangs at the upper part of the cell, which is filled with dilute solution of sulphate of zinc. The copper cell is filled with a saturated solution of copper sulphate, and crystals of this salt, as large as a small hazel-nut, are placed at the bottom. This battery has been adopted by the Post Office. The expenditure in copper sulphate is about 1.45 lb. per cell per annum.

Several other modifications of the Daniell have been employed; among the most important is the so-called

49. *Minotto Battery*.—This battery consists of a glass jar, at the bottom of which lies a disc of copper soldered to a wire, covered with varnish or percha, which extends to the top of the jar. Above the disc is a layer of coarsely-powdered copper sulphate, covered with a layer of clean sand; the sulphate and the sand are separated by a disc of cloth or porous paper. The jar is nearly filled with soft water, and a piece of unamalgamated zinc, sufficiently large to last as long as the copper sulphate, is laid upon the surface of the sand. The wire connected

to the zinc must be so arranged as to allow it to follow the sand as it is lowered in the jar by the gradual solution of the copper sulphate.

Sawdust which has been boiled is often used instead of sand, and in some cases a glass tube passes through the centre of the sand or sawdust, by which fresh sulphate can be added.

Gas is frequently given off on the surface of the zinc, which covers the metal so as to protect it from the liquid, and causes polarization. If the plates be cast wedged-shaped, and hung with the edge downwards, the gas passes away more freely. This action of the gas renders the current somewhat unsteady, especially when it is used for delicate experiments, and it must be prevented. This battery is well adapted for cable-testing, and is used for working the Atlantic cables.

50. *Graphite Battery*.—The following is the best form of graphite, or gas carbon battery, with amalgamated zinc and dilute sulphuric acid, 1 part to 12 of water.

The carbon plates are pickled a few days in strong sulphuric acid and water, drilled and electrotyped¹ with copper at their top; this copper is then tinned, the connecting strap is riveted to it with tinned rivets and then soldered. The carbon is then platinized by the electrotype process, using a straw-coloured solution of platinum, with a battery of 4 cells. A small slipper of percha is fixed to the bottom of the zinc plate, to contain a little mercury for the purpose of maintaining the amalgamation by capillary action.

When the jar is considerably deeper than the plates, so that the solution of zinc sulphate can fall to the bottom as it forms, leaving the lighter acid at the top, this battery lasts a long time. It is, however, not suited for producing a continued current.

51. *Sand Battery*.—Amalgamated zinc and copper placed in a cell filled with pure, sharp sand, moistened with dilute sulphuric acid (one of acid to twelve of water), form a

¹ To ELECTROTYPE.—Place the part of the carbon plate to be coppered in a saturated solution of copper sulphate, connect it to the zinc of a single Daniell cell, place a copper plate in the solution so as not to touch the carbon, and connect it to the copper of the cell.

convenient portable battery. When the battery is not in use, the acid dissolves a little copper, which is again deposited on the plate when the battery is worked.

Care must be taken that the sand is quite free from iron, lime, or other impurities, and that the water is freed from lime. The acid and water should, therefore, be mixed before it is wanted, when the lime will fall down in a white powder. Lime encrusts the zinc, and spoils the battery.

There is very little room for liquid, so that, if in constant action, the sand soon becomes choked with zinc sulphate. This can be removed by soaking the trough in water, and draining it carefully.

52. *Modified Smee Battery*.—Scraps of zinc are laid in a saucer containing mercury, placed at the bottom of a glass jar, and a plate of platinized silver (silver coated with platinum by the electrotype process) is hung vertically above. The jar is filled with dilute sulphuric acid. It is very constant, but needs rest after each signal, because the zinc sulphate formed by its action forms a stratum over the zinc saucer, protecting it for a time from the action of the acid. A piece of percha-covered wire, bared for a $\frac{1}{4}$ -inch, dipping into the mercury, forms the zinc connection.

53. The *Leclanché Battery*, which has been recently introduced, consists of a zinc rod placed in a solution of the ordinary commercial sal-ammoniac (ammonium chloride); the negative plate is a piece of carbon surrounded by a mixture of gas carbon and the *needle form* of manganese peroxide contained in a porous jar. Both the manganese and carbon must be broken in small pieces, and sifted to remove the dust, as the presence of fine powder interferes with the action. The action of this battery is to form zinc chloride, which is soluble in sal-ammoniac; the manganese peroxide is reduced to a lower oxide, and ammonia is formed in small quantities. Thus, after an interval of time, generally twelve months, the zinc and peroxide must be replaced and the sal-ammoniac renewed. In practice, for every 50 grains of zinc dissolved 100 grains of sal-ammoniac are consumed, and 100 grains of manganese peroxide are reduced. The electromotive force of this battery is very great. It is equal to about

1.6 of a Daniell cell, so that 10 Leclanché cells are equal to 16 of a Daniell.¹ The internal resistance is also very much less than that of a Daniell cell, and therefore its "quantity" considerably greater; but, on the other hand, when placed in short circuit it polarizes very quickly, so that it cannot be used for permanent currents or as a local battery.

There is no waste of material when the battery is not in action, so that, if the evaporation of the liquid is prevented, it may be allowed to remain untouched for months without losing power. It is therefore more suitable than the Daniell, where constant attention cannot be provided, and where the telegraph is not in constant use; and for electric bells. Several points need attention in the setting up of this battery. The carbon plates are capped with lead, in order to provide an attachment for the binding screws, for copper would be attacked by the ammonia. But it is found that a salt of lead is formed between the carbon and the metal, which in time insulates them from each other. To prevent this, the carbons are first well dried and heated to about 120° Centigrade; their tops are then dipped in melted paraffin and covered with lead, great care being taken to press the lead closely into contact with the carbon.

It is not absolutely necessary to amalgamate the zinc, but the amalgamation tends to prevent the formation of crystals upon its surface. When the sal-ammoniac has nearly been removed from the liquid, it is unable to dissolve the zinc chloride, and in consequence becomes milky; more ammonia salt must then be added. When the battery begins to fail, the porous jars may be soaked in water, but this process cannot be adopted a second time. The cell should not be filled above two-thirds of its depth. The connecting straps must be varnished.

54. The *Marie-Davy Battery*, constructed with zinc, carbon,

¹ Other trials with new batteries have given even a more favourable comparison, the electromotive force as shown by a Thomson electrometer being as 25 to 40, and the strength of signal through resistance as 27 to 40. But while the Daniell was capable of affording a steady constant current on a circuit of very small resistance, the Leclanché fell from 60 to 35 in half a minute. But with a higher resistance the current was steady. The electromotive force of the Leclanché as compared with the Minotto is as 160 to 300.

and a solution of the white crystalline bisulphate of mercury, was till lately almost exclusively employed at the Central Office of the French Administration of Telegraphs in Paris. It is a very powerful battery, and produces excellent effects, but its maintenance is expensive, and it is not adapted for continuous work, owing to the slow solubility of the salt. It is self-amalgamating, and, owing to the high conducting power of the solution, its quantity is very considerable—or, to speak more correctly, its resistance is very small, while its tension is such that 8 of its cells are equal to 12 of Daniell's.

Ordinary single fluid batteries, owing chiefly to polarization, do not produce constant currents for two minutes together, and they are only adapted for the production of momentary effects, such as the sounding of gongs, ringing of bells, firing fuses, or dropping time signals.

55. The batteries of Grove and Bunsen are not used in England for telegraphic purposes; they have been tried on the Continent, but in almost every place have given way for the Daniell, the Marie-Davy, or the Leclanché. They are, however, used largely in America.

56. *Secondary Batteries.*—Polarization (34, 35) is employed in some cases to produce a powerful but transient current. The principle is well shown in Grove's "Gas Battery." Two strips of platinum are placed side by side in acidulated water, and are connected to the two poles of a battery sufficiently powerful to decompose water (34), called the *primary* battery. Oxygen is given off upon one of the strips, hydrogen upon the other; and as neither hydrogen nor oxygen have an affinity for platinum, both gases remain upon their respective metal plates, forming, when the primary battery is removed, a so-called *secondary* battery of platinum in oxygen opposed to platinum in hydrogen, the current resulting from which will be in the opposite direction to that of the primary or decomposing battery.

57. Lead, or any other metal, with but a slight affinity for oxygen, may be used instead of platinum; and in practice, a number of plates of the same metal, usually thin sheet-lead, are arranged in series as a battery in cells, filled with dilute sul-

phuric acid, or with sawdust moistened with dilute acid. When a current from another battery is made to pass through it, water is decomposed, its oxygen forms lead peroxide, coating the plates on one side of each cell, while its hydrogen spreads over the opposite plates, polarizing the lead plates, and forming a battery of lead with hydrogen, and lead with peroxide of lead. When the primary battery is removed, and the poles of the secondary battery are connected, the action of these products causes a current in a reverse direction to that of the primary battery. The duration of this *secondary* current depends, within certain limits, upon that of the primary.

58. A zinc-carbon battery upon this principle was at one time used for distributing the time-signals from the central station of the Postal Telegraphs, but has been superseded by the Leclanché. Each *alternate* partition of a gutta-percha trough, divided into cells, is cut down to within about half an inch of the bottom, and the two divisions thus formed are filled with mercury, care being taken that the two portions of mercury do not touch. Small pieces of zinc are placed in one portion, and a plate of graphite (gas carbon) in the other, as the two plates of a battery; and the cell is filled with dilute sulphuric acid. The necessary connection between one cell and another is formed by platinum wire passing through the percha into the mercury. To excite it, it is connected, carbon to copper and zinc to zinc, with a battery of about twice the number of cells for about half an hour. This arrangement produces a very energetic current for a few seconds, and will give an effective signal upon ten or more long circuits.

59. When there is no local action, *the amount of decomposition in each and every cell of a battery is equal.*

That is to say, if in one cell of a series of 100, one ounce of copper sulphate is decomposed, exactly one ounce will be decomposed in each of the other 99.

60. When a battery is in good condition, each cell produces by its own action the requisite decomposition; but if a cell is weak, it must be assisted, as it were, by the rest; so that instead of adding to the force of the battery it diminishes it. As old batteries contain exhausted charges and foul plates, they should never be placed in series with new ones.

61. If all the cells are not alike in size, or if the plates in some are smaller than those in others, the smaller will be first exhausted. When a pair is *reversed*, joined copper to copper instead of copper to zinc, its solutions are not only decomposed by the remaining cells, but the latter must also overcome the electromotive force of the reversed cell, which is obviously contrary to that of the battery. If in a series of four cells one be reversed, it will nearly neutralize the effect of the remaining three.

62. In a Daniell battery, the action of the current deposits on the copper plate one *equivalent* or 25 parts of metallic copper for each *equivalent* or 26 parts of zinc dissolved. As copper sulphate contains 25.5 per cent. of metal, for every 100 ounces of sulphate decomposed 25.5 ounces of copper are deposited, and 26 ounces of zinc dissolved. The same law applies to the decomposition of that portion of copper sulphate which penetrates the zinc cell, and, attacking the zinc plate *locally*, forms the deposit which falls to the bottom of the cell.

63. In setting up a Daniell battery the following precautions are necessary:—The crystals of copper sulphate should be the size of a hazel-nut; if large crystals are crushed, so as to reduce them in part to powder, they form a compact mass, which dissolves so slowly as to be almost useless, and cannot be removed without danger of breaking the cell.

64. The copper connecting-straps, wires, and binding-screws must be perfectly clean. The end of the strap which is cast into the zinc should be tinned, to ensure perfect contact.

The plates should be alike in size, and immersed equally in the liquid. The coppers should be carefully brightened, and the zincs brushed clean. Copper plates, if very dirty, may be cleaned by being made red-hot and dipped into weak ammonia. A piece of the "card" used in cotton manufactories is the best brush for battery plates.

65. If the water contains lime, it decomposes a part of the sulphate, forming a cloudy or jelly-like deposit. To prevent this, a few drops of dilute sulphuric acid should be added, and the water allowed to stand to deposit the lime. The copper cells should be charged with saturated solution of copper sulphate

before any liquid is poured into the zinc cells, so that the pores of the porous divisions may be filled with a *good conductor*, for otherwise the action of the battery will be checked.

When the zinc cells of a battery are charged with water only, it rarely assumes its full power until it has been at work for two or three days; but it can immediately be set in full action by the addition of solution of zinc sulphate, provided the porous cells or divisions are well saturated with the copper solution.

66. It is false economy to work Daniell batteries after the zinc or the porous cells have become coated with copper, or to use cracked porous cells.

67. When a battery is cleaned the plates should be removed, and the divisions thoroughly rinsed and washed out, the plates well scraped and scrubbed, defective porous cells and zinc plates removed, and the battery again carefully charged.

In re-charging the battery, the liquid from the zinc cells may be used. It may be withdrawn by a syringe before the battery is cleaned, and (42) placed in a vessel containing a few pieces of zinc to reduce any copper that may remain in solution. When the battery has been cleansed, the plates replaced, and the copper sulphate deposited in the cells, the solution may be distributed equally throughout the zinc cells—diluted if necessary (72).

68. Batteries must be kept in a dry place, and be *well-insulated*, or part of the current will escape to the earth. If the room be too warm, the water will evaporate. Cold stops their action, so that they must never be placed where they are not perfectly secure from frost.

69. Porous cells, or troughs fitted with porous plates, if set aside after they have been used, must be kept moist, or the sulphate of zinc contained in the pores will crystallize and destroy them, by an action similar to that of frost.

70. Both zinc and copper salt must be of the very best quality, the salt free from iron, which is the principal impurity, and the zinc from lead.

Test for the Purity of Copper Sulphate.—To detect iron, dissolve the crystals in water, and add liquid ammonia; this

will at first precipitate both the copper and the iron, making the solution appear cloudy; but if more ammonia is added the copper will be re-dissolved, forming a bright blue solution, while the iron will remain as a brown powder. Good sulphate should contain a mere trace of iron. The following are analyses of the quality supplied to the Post Office:

Crystallized copper sulphate	. 99.66—98.48	per cent.
Iron sulphate	 0.09—0.12	„
Extraneous water	 1.25—1.40	„

Zinc.—Zinc contains carbon, lead, and iron; the latter is partly derived from the melting-pots, which should be lined with fire-clay. Four parcels submitted to analysis contained respectively:—

Zinc	. 99.27	. . 98.76	. 97.85	. 98.85	per cent.
Lead	. 0.67	. 1.18	. 2.05	. 1.13	„
Iron	. 0.06	. 0.06	. 0.10	. 0.02	„

The purest sample was Silesian spelter.

71. In order to ascertain the working condition of a battery, it should be tested with a galvanometer wound with two or three yards of thick wire ("Quantity Detector"), or with an ordinary detector, whose sensitiveness is reduced by a "shunt," so as to allow but a very small portion of the current to flow through its coils. One cell in good order will give as large a deflection as 100 of the same kind, but if any one of the 100 is defective, the deflection will be less than that given by a single good cell; one bad cell will spoil the entire set.

The trough which is faulty should first be found, and then the particular cell of that trough, which may be cut out by connecting the plates with wire (45).

72. The following are the most usual faults of the Daniell:—

Weak current.—Copper sulphate exhausted. Zinc sulphate solution too strong, perhaps crystallized upon the zincs; it should never be allowed to become more than half saturated. Zincs covered with a deposit of copper. Terminals corroded, or

encrusted with dry sulphates (this fault is very frequent). A cell partly empty, the liquid drawn off by the syphon-like action of the crystals of zinc sulphate (46). Dirty connections; battery making earth from damp; wires badly insulated, making earth or contact. Filaments of deposited copper extending across from the copper to the zinc plate.

Intermittent Current.—A battery plate broken, touching at times, and at other times becoming separated. Loose battery wire.

No Current.—Broken battery wire or plate; empty cell; battery wires in contact, perhaps where stapled down to the table or wall; or wire in contact with earth.

It often happens that the copper plate is eaten away near the surface of the solution when the supply of copper sulphate is exhausted.

PART II.

RESISTANCE AND THE LAWS OF THE CURRENT.

73. WHEN the poles of a battery are connected by a conductor, the electricity is assumed to flow as a *current* from the zinc to the copper plate through the battery itself; and from the positive or copper to the negative or zinc pole, through the conductor (23) which connects them.

A telegraph *circuit* (so called) consists of the battery, the instruments, and a conductor composed of the line-wire and the earth. A return-wire is used instead of the earth when the circuit is very short.

74. Owing to the rapidity with which the electric force is propagated in the form of a current, when not influenced by induction, any effect which can be produced on a short circuit can be produced at a distance at the same instant of time, subject to a diminution of force arising from causes which diminish the *quantity* of electricity or force of the current before its arrival at the distant end, and thus weaken the signal; for the strength of all telegraphic signals, including the deflection of the galvanometer, depends upon the *quantity* of electricity passing through the receiving apparatus in a given time, which is itself governed by the *electromotive force* of the battery, the *resistance* the electricity has to overcome, and the losses from defective insulation (189). If the electromotive force of the battery is increased, it is with the view of overcoming the resistance of the circuit, so that more electricity may pass in a *given time*. If two batteries be compared, it will be found that

the strength of the signal through a large resistance is exactly proportional to their potentials as shown by the electrometer.

75. As stated by Ferguson, the *electromotive force* of the voltaic pair is proportional to the intensity of the chemical action; the *current strength* (quantity) to the amount of this action, or the quantity of zinc dissolved in a given time; and the *resistance* is that which prevents the former from generating the latter.

76. *Resistance* is the obstruction offered to the current by the bodies through which it is made to pass, and is the opposite, *reciprocal*, or converse of their conducting power or *conductivity*. When resistance is so great as to approach infinity, it becomes *insulation*.

77. All bodies do not conduct equally well; each has a certain *specific resistance*—that is, a resistance peculiar to itself.

Silver, for instance, has less resistance and higher conductivity than any other known substance.

If pure silver be taken as having a conducting	
power or <i>conductivity</i> of	100·0
Pure Copper (hard drawn) will be equal to .	99·9
„ Gold (hard)	78·0
„ Zinc (pressed)	29·0
„ Platinum (soft)	18·0
„ Iron (soft) (nearly)	16·8
„ Tin (soft)	12·3
„ Lead	8·3
„ Mercury (commercially pure)	1·6

The figures given are according to Matthiessen's most recent determinations. The conducting power of the *metals of commerce* differs very widely from the values given in the text. Impurities always lessen conductivity.

Saline and acid solutions, though the best of liquid (non-metallic) conductors, offer enormously more resistance than metals, thus:—

If the resistance of copper be 1,
That of 1 part sulphuric acid to 11 of water will be 1 million,

That of a saturated solution of zinc sulphate	
will be	16 millions,
That of a saturated solution of zinc sulphate	
diluted with equal parts of water will be .	14 millions,
That of a saturated solution of copper sulphate	
will be	17 millions
And of distilled water	6,754 millions.

78. If a constant battery be connected with a galvanometer by wires of various thicknesses and lengths, it will be found that the greater the resistance introduced into the circuit the less the needle is deviated, showing that the current is enfeebled. The relative resistances of different wires may thus be compared. If two wires introduced in turn into the circuit produce the same deflection, their resistances are equal, whatever be their gauge or length.

Instead of comparing the resistance of one wire with another arbitrarily, it is convenient to fix on some one standard to which all may be compared. For instance, if one mile of copper wire 50 mils¹ diameter (the gauge ordinarily used for tunnels and underground work) be placed in circuit, and the deviation of the needle noted, we can find by trial how much copper wire or German silver wire (the resistance of which is greater than copper) must be used to produce the same deflection with the same battery and galvanometer. This wire, if wound on a bobbin and preserved, becomes our mile measure. If a number of bobbins are filled with fine wire equal in resistance to various lengths of the thicker wire, we obtain a *rheostat*, or set of resistance coils, adapted to this standard.

79. Several standards or *units* of resistance have been proposed. The unit adopted by the electricians of this country is that determined by a Committee of the British Association, and is called the "*ohm*" (from Ohm, who first ascertained the laws of electrical resistance), and sometimes the "*B.A. unit*." It

¹ As there is no authorized standard for the Birmingham wire gauge, precision as to diameter can only be obtained by stating it in decimals of an inch. The word *mil* (introduced by Clark), means a *thousandth of an inch*, so that 50 mils stands for 0.050 inch. It must not be mistaken for *millimetre*.

must be understood that the *unit* is a measure of *resistance*, in the same way as the yard, inch, or mile is the measure of *length*.

"Siemens' unit" is the resistance of one metre¹ of pure mercury, of one square millimetre section, at a temperature of 32°. The Siemens' unit being taken as 1,000, the ohm will be 956; in other words, the ohm is 4·4 per cent. smaller than the Siemens. The French unit is one kilometre of the iron wire in general use, four millimetres diameter, and its value is about nine ohms.

All experiments for resistance can as well be performed with an artificial line made up with resistance coils as on the actual telegraph, provided we do not require to take into account the effect of bad insulation, or induction.

80. The resistance of metals increases with an increase of temperature, while that of saline solutions decreases, so that during very accurate measurements the temperature must be kept constant; and it is necessary to use for resistance coils a metal affected a little as possible by variations of heat.

Matthiessen states, in the Report of the British Association Committee on Standards of Electrical Resistance, 1863, that pure iron² varies between zero and 100° Centigrade (32° and 212° Fahrenheit) as much as 39·2 per cent. other pure solid metals 29·3, while German silver varies only 4·4 per cent. (See Table 10.) It is therefore the best of the ordinary materials for the purpose. An alloy of silver with 33·4 per cent. of platinum varies only 3·1 per cent.

81. The comparative purity of a metal affects its resistance most materially. In copper this is particularly marked—so much so, that the copper wire of 50 mils gauge now used conducts nearly as well as older wire of 65 mils gauge. Lake Superior copper, according to Matthiessen, has a conducting power of 92·6 per cent. (pure copper being 100), Burra Burra

¹ The metre is equal to 39·37 inches; the millimetre, 0·039 inches.

² No. 8 iron wire (·170 in.) increases in resistance between 32° and 60° F. 0·770 ohm per mile, and No. 11 (·125) 1·528 ohms. This is 20·97 per cent. for each degree, and very nearly agrees with Matthiessen's determination for pure iron, 21·80 per cent.

83·7, Rio Tinto only 14·2 per cent. It is therefore necessary to test carefully the specific conducting power of all copper wire supplied for telegraphic purposes. It should not be less than 90 per cent., for wire of this quality can readily be obtained. For cables and for the coils of apparatus the conductivity should be over 90 per cent.

82. The resistance of a solid conductor, such as a telegraph wire, is in direct proportion to its length, and in the inverse proportion of its weight per mile. Ten miles of wire offer tenfold the resistance of a single mile of the same wire, and a wire weighing one pound per mile has tenfold the resistance of one which weighs ten pounds.

The resistance lessens as the size of the wire increases, in the ratio of the square of its diameter. It will take four wires $\frac{1}{8}$ th of an inch thick to make up the substance of a single wire $\frac{1}{4}$ of an inch thick, and the $\frac{1}{4}$ -inch wire will offer only a quarter of the resistance of the $\frac{1}{8}$ -inch wire, the lengths being equal. Four miles of the thick wire will conduct as readily as one mile of the thin. If the thickness of the wire be increased to $\frac{3}{8}$ -inch, nine miles will for the same reason offer the same resistance as one mile of the thin conducting wire (nine being the square of three).

Hence the advantage of a thick line wire. If the battery and instrument offer a comparatively feeble resistance, as good a signal can be produced at nine miles' distance with a wire $\frac{3}{8}$ -inch diameter, as at one mile with a wire only $\frac{1}{8}$ th thick. A further advantage is, that a thick wire need not be insulated so carefully as a thinner one.

The resistance of the iron wire most generally used is—

	In.	
¹ 240 mils (No. 4)	0·240—	7·8 ohms per mile.
170 „ („ 8)	0·170—	13·5 „
125 „ („ 11)	0·125—	23·0 „

“Homogeneous” metal and steel have a higher resistance.

¹ This must be considered merely an approximation ; a very slight difference in the gauge or in the temperature will cause a great variation in the resistance. A careful test recently gave 14·28 ohms per mile for wire of 170 mils after erection on the line.

83. It will be understood that the resistance of a telegraph circuit is the sum of the resistances of its several parts; the battery, the line-wire, and the coils of the apparatus.

The effect of inserting a length of thinner wire on the line is simply to increase its resistance, and to make the line, as it were, so much the longer.

When two wires or two batteries are connected side by side the resistance will be halved, if they are precisely similar in all respects; but if they are dissimilar, their joint resistance follows the law stated in the chapter on Insulation.

As the battery itself forms part of the circuit, its resistance is a matter of great importance. This resistance is compounded of that of the liquids with which the battery is charged, and that of the porous divisions which separate them. It is modified by the size of the plates, for the larger the plates the greater the area of the liquid, and the less its resistance; and by their distance from each other, for the closer they are placed, the shorter is the liquid conductor. As liquids are bad conductors (76), the size and distance of the plates have a very great influence on the resistances of the cell.

The material of the porous divisions is generally a non-conductor, so that the current passes entirely by its pores. The introduction of porous divisions, therefore, increases the resistance of the cell, by decreasing the area of the liquid.

84. As a battery is merely a number of cells connected in series, its resistance increases in direct proportion to the number of cells composing it.

The electromotive force also increases in the same proportion. Ten cells will have tenfold the force of one cell (25), and ten times the resistance.

85. Every part of a circuit (including, of course, the battery) whatever be its form, nature, or resistance, is traversed in a given time by equal *quantities* of electricity; just as in a river the same quantity of water passes any given part of the channel each minute, whether the stream be narrow or broad, shallow or deep; because each part is supplied by that which precedes it, and in the like manner supplies the succeeding length.

86. The current through the circuit will equal the electro-

motive force of the battery, or the difference of potential between the two poles caused by the electromotive force, divided by the sum of the resistances of the battery, conducting-wire, and apparatus for signalling, forming the circuit.

Call the electromotive force E
 „ battery resistance r
 „ apparatus and line resistance l
 „ total resistance $(r + l)$ R
 And the strength of the current or quantity of electricity passing each second } C

$$\text{Then } C = \frac{E}{R + L}$$

This is one of Ohm's celebrated laws, and is the basis of all the mathematical laws of electric currents; it shows that the less the resistance $(r + l = R)$, the more current (C) will pass in a given time; or in other words, the greater will be its quantity.

87. Take a battery of 24 cells, whose resistance (r) is 120 ohms, and whose electromotive force (E) is 10 per cell, or 240 for the 24 cells.

A. Connect it to a "quantity" galvanometer (59), whose resistance (l) is so small that it may be neglected. Here, as the only resistance in the circuit is that of the battery itself, $R = r$. The effective strength or quantity of the current will, in this

$$\text{case, be } \frac{E}{R} = \frac{240}{120} = 2$$

$$\text{Take off half the battery } \frac{\frac{1}{2}E}{\frac{1}{2}R} = \frac{120}{60} = 2$$

$$\text{Remove all but a single cell } \frac{\frac{1}{24}E}{\frac{1}{24}R} = \frac{10}{5} = 2$$

Thus, when there is an infinitely small *external resistance*, or when the conductor connecting the poles of the battery is so large that it offers no appreciable obstacle to the current, one cell will give as large a deflection as any number of similar

cells that may be connected in circuit; for *each cell brings its own resistance with it*, and the increased electromotive force is solely occupied in overcoming this increased resistance; if, then, the *resistance* of a circuit be increased in the same proportion as the number of cells in the series, the deflection will remain unaltered.

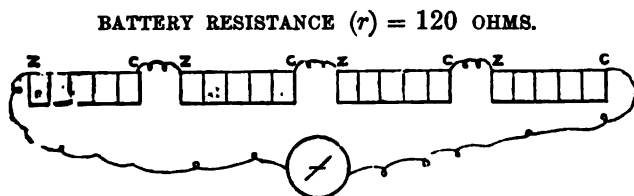
This is expressed generally thus—If, under such conditions, we have n cells (n representing the number of cells in the battery), $\frac{nE}{nR}$ will equal $\frac{E}{R}$.

B. But if the same battery be tested with a detector wound with fine wire, whose resistance (l) is 120 ohms—

$$\begin{array}{llll} \text{With 24 cells} & \frac{r+l}{E} & = & \frac{240}{120+120} = 1.0 \\ \text{With 12 cells} & \frac{\frac{1}{2}E}{\frac{1}{2}r+l} & = & \frac{120}{60+120} = .66 \\ \text{With 6 cells} & \frac{\frac{1}{4}E}{\frac{1}{4}r+l} & = & \frac{60}{30+120} = .4 \end{array}$$

Here the deflection increases with the number of cells, but not exactly in proportion to the number added, for *each cell brings its resistance with it, and thus lengthens the circuit*.

88. Connect the same battery to a wire, the resistance of which, including the galvanometer, is but 20 ohms.



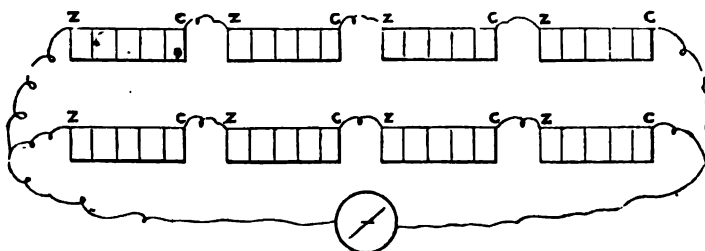
LINE AND GALVANOMETER (l) = 20 OHMS.

FIG. 4.

The quantity of the current, as measured by the deflection of the galvanometer, will be $\frac{240}{120+20} = 1.7$.

89. "Double the quantity,"¹ as it is technically termed, by placing two similar sets side by side, connecting the two terminal zincs together, and the two terminal coppers, thus:—

$$r = 60 \text{ OHMS.}$$



$$l = 20 \text{ OHMS.}$$

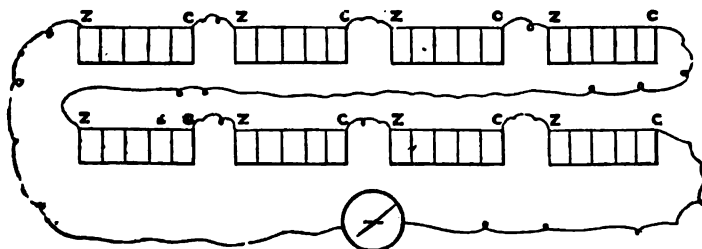
FIG. 5.

The electromotive force of the battery will be the same as with the single set, while its resistance will be halved, because the size of the plates is doubled.

Therefore the current will be $\frac{240}{60 + 20} = 3.0$, or nearly double.

90. Connect the two sets *in single series*, thus:—

$$r = 240 \text{ OHMS.}$$



$$l = 20 \text{ OHMS.}$$

FIG. 6.

¹ This operation is more properly called connecting the batteries in *multiple arc*, or in *parallel series*.

The electromotive force will be doubled, but the battery resistance will also be doubled, and

the quantity will be $\frac{480}{240 + 20} = 1.9$ nearly.

or only .2 greater than with half the number of cells; for the extra number of cells are almost entirely employed in overcoming the resistance they have brought with them.

91. Connect the battery to a wire and galvanometer, whose resistance (l) is 1,000 ohms.

With 24 cells the quantity will be $\frac{240}{120 + 1000} = 2.1$.

With two sets of 24 cells, arranged for "quantity," or in parallel series, $\frac{240}{60 + 1000} = 2.2$, or nearly the same as with one set.

But when the two sets are arranged in single series $\frac{480}{240 + 1000} = 3.9$ nearly, or almost double the effect of the original number of cells.

92. Thus, the *greater* the resistance of the *line*, the *less*, proportionately is the effect of the resistance of the *battery*; and the *less* the resistance of the *line*, the *greater* the effect of the resistance of the *battery*.

93. On a short line, or a badly insulated long line, the size of the plates may be increased with advantage, for, the resistance being less, the battery "works the harder," and is sooner exhausted.

On a long circuit, there is little or no advantage in increasing the size of the plates *if the line be well insulated*, but great advantage, up to a certain limit, in increasing their number.

94. It sometimes happens that a supply of large cells, or batteries of small resistance, is not at hand for a faulty line, or a local circuit. The following calculation will show how to produce the greatest possible effect with a given number of equal small batteries for a temporary purpose:—

Suppose the line has a resistance of 80 ohms:

The number of cells 120, in 12 troughs of 10 cells :

The resistance of each trough 60 ohms :

The electromotive force of each trough 100, as before.

(i.) If connected in single series—

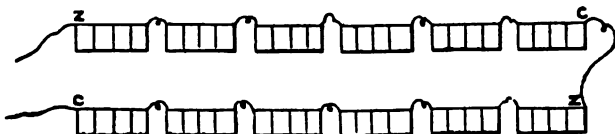


FIG. 7.

The electromotive force will be. . . $12 \times 100 = 1200 = E$.

The resistance of the batteries. . . $12 \times 60 = 720 = r$.

The resistance of the line $80 = l$.

$\frac{E}{r + l}$, or the electromotive force divided by the total resistance,
gives $\frac{1200}{800} = 1.5$.

(ii.) If connected in two parallel series of 6 troughs each—

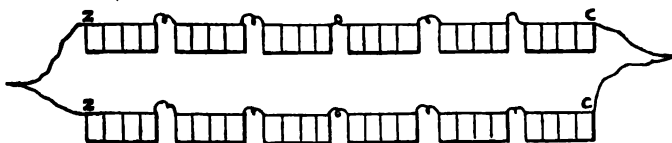


FIG. 8.

The electromotive force will be $6 \times 100 = 600$

The resistance of the batteries $\frac{720}{2 \times 2} = 180^1$

The resistance of the line 80

And the current in circuit . . $\frac{600}{260} = 2.3$

¹ The resistance of the battery is reduced to one-half, because there are but half the number of cells. The resistance is again halved, because each cell is doubled in size. Hence the resistance of the doubled series is $2 \times 2 =$ one-quarter of the original resistance.

(iii.) If connected in 3 sets of 4 troughs.

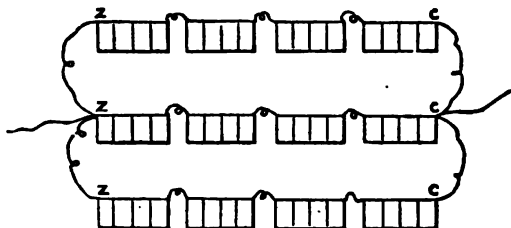


FIG. 9.

Electromotive force . . . $4 \times 100 = 400$

Resistance of batteries . . . $\frac{720}{3 \times 3} = 80$

Resistance of line 80

The current in circuit . . . $\frac{400}{160} = 2.5$

(iv.) If connected in 4 sets of 3 troughs—

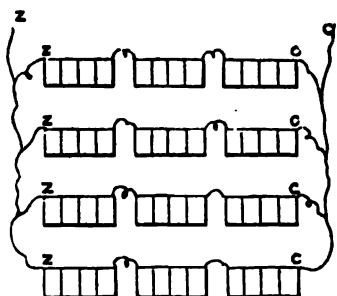


FIG. 10.

Electromotive force . . . $3 \times 100 = 300$

Resistance of batteries . . . $\frac{720}{4 \times 4} = 45$

Resistance of line 80

The current in circuit . . . $\frac{300}{125} = 2.4$

The greatest effect, then, of a given number of cells is produced when they are so arranged that the battery resistance

equals that of the line, as in No. iii.; and consequently, when a battery is placed on that line which is best adapted to it, the current it will give is exactly one-half of that which it gives when on short circuit, or when the resistance of the *line* is nothing.

95. Theoretically, then, the maximum effect of a certain given surface of zinc is attained when it is divided into so many plates that the resistance of the battery shall equal that of the line. It has been argued from this, that the plates ordinarily used may be reduced in size with economy.

For a single experiment, such as testing a tunnel, a battery of small plates constructed on this principle is useful; not so for continued use on a circuit; for in practice the resistance of a line of telegraph constantly varies. The battery, if calculated for a perfect state of insulation, will not only theoretically, but practically have too much resistance when a fault occurs on the line, or when rain comes on. Besides this, causes which affect the constancy of a battery, such as the fouling of the plates, polarization, &c. &c., have a greater effect on the small pairs, because they are spread over a small surface; while, if the plates were doubled in size, the deposit or the gas would have double the space to cover, and would do less harm.

96. The cells should be so large, that the battery shall offer considerably less resistance than the line. It should have sufficient electromotive force to overcome the resistance of the line, and be able to supply sufficient electricity to make up for the losses on the way.

97. There is a disadvantage in making up a "quantity battery" by connecting batteries of small plates side by side. Unless they are perfectly equal in power and conductivity, the stronger will have a tendency to send a current back through the weaker; for a battery must not be considered merely as a producer, but also a conductor of a current.

When Daniell's batteries are thus associated for "quantity" or connected in parallel series for a considerable time, one must, sooner or later, overpower the other; when this occurs, the copper sulphate of the weaker battery is driven through the porous cells, and copper is deposited on the zinc, annihilating the electromo-

tive force and producing great local action. Hence it is much better to use one plate of 32 square inches, than two of 16 square inches placed side by side.

THE EARTH.

98. It was at one time imagined that the earth completed the circuit precisely in the same manner as a return wire.

Another view is, that as whenever one kind of electricity is produced, an equal quantity of the opposite is also produced; and as both electricities are ultimately transferred to the earth, they neutralize one another, because of the earth's perfect conductivity.

The following explanation may be given :—It has been shown that the cause of the transfer of electricity from one point to another is the *difference of potential* between those points. When two small insulated and unelectrified conductors are placed each in contact with one of the poles of a battery, they are raised to the potential of the battery, it having furnished a current sufficient to charge them, but not of *sufficient duration* to move a galvanometer needle.

If the conductors are enlarged, the time occupied in charging them will increase, until, as they are still further enlarged, a limit will be reached at which the flow of electricity into them *will last long enough* to affect the galvanometer; and when the conductors become infinitely long or infinitely large, the time occupied in charging them also becomes infinite; or, in other words, the current will pass precisely as if the poles were connected, and this whether the conductors remain insulated or are connected together.

Thus, when the extremities of a telegraphic circuit are connected to the earth, which is an infinitely large conductor, and is always at the zero of potential, the difference of potential between them and the earth is maintained, notwithstanding the flow of electricity; for it is as impossible to alter the electric condition of any one point of the earth, by our feeble means (unless,

indeed, where the soil insulates, and here the telegraph would not act) as it is to alter the level of the sea by pouring in or pumping out water from it.

The earth acts also as an ordinary conductor, and, where the soil is very dry or rocky, offers resistance; but if two earth-plates be buried in the soil, the resistance of the portion included between them does not vary in the ratio of their distance, as it would if the soil between them were enclosed in a box. Blavier¹ gives the following results, which were obtained by Matteuci; the size of the plates being the same in each case:—

		Resistance.		Resistance.	
Plates 1 yard apart on the level plain, 68, on a mountain, 152					
" 5	"	"	97	"	—
" 10	"	"	102	"	222
" 20	"	"	109	"	—
" 50	"	"	120	"	531
" 100	"	"	—	"	849

The soil of the plain was probably in itself a better conductor and damper than the rocky soil of the mountain.

The resistance was found to diminish inversely as the depth to which the plates are buried.

When buried 4 inches the resistance was 91.

" 10	"	"	83.
" 40	"	"	74.
" 80	"	"	70.

The size of the plates has the greatest influence on the resistance.

If a plate containing 1 square foot of surface gives a resistance of 174,

A plate of 4 square feet will give a resistance of 140.

" 16	"	"	81.
" 25	"	"	47.
" 32	"	"	31.

¹ "Télégraphie Électrique," par E. E. Blavier.

But after a certain *size*, varying with the conducting power of the soil around the plates, the resistance remains constant. In the sea this limit is very quickly reached.

After a certain *distance*, varying with the conducting power of the soil and the size and depth of the plates, a further increase of distance makes no difference in the resistance.

Conduction does not take place solely in the direct line between the two plates, but extends in curved lines on all sides. It is thus easily seen why the resistance decreases with the depth to which the plates are buried, is less on a plain than on a mountain, and is greater when a portion of soil is isolated by being placed in a box, for then conduction takes place only in the direct line, and there can be no diffusion. Its resistance then follows the same law as that of any other substance, depending on its dryness or dampness, its nature, and its length and section.

On short lines the resistance of the earth is a matter of the greatest importance.

If the earth terminals of the several circuits or wires are connected to one and the same earth-plate, it becomes a question of comparative resistance whether a current sent on one wire shall pass direct to the earth, or shall divide between the earth and the other wires. The earth-plates should in all cases be large, and be buried deep in soil *wet at all seasons*.

It sometimes happens that an "earth cannot be found" in places where there is but a thin layer of soil covering rock, or where the soil is constantly dry.

Instead of connecting all the wires to the same earth-plate, use separate plates buried fifty yards or more apart, so that the resistance of the soil between the plates may be greater than the resistance of the portion intervening between the stratum in which they are buried and the better conducting soil below it.

When this plan cannot be carried out, the resistance of the shorter circuits may be increased by resistance coils, in order to lessen the tendency to leakage from the circuit of greater resistance to that of lesser resistance, through the earth-wire.

To test an earth-plate, send a current on one wire, and place

a sensitive galvanometer on the shortest of the others; one fixed on separate poles, if there is more than one line. If no current passes through the galvanometer, the earth is perfect.

A water or gas-pipe is preferable to a plate, because of its larger surface. Care must be taken to connect the earth-wire to the main street gas-pipe, as the joints indoors are frequently rusty, or packed with white lead, and leaden gas-pipes have been fused and the gas set on fire by a lightning discharge between them and adjacent conductors; it is therefore bad practice to carry leading-in wires within two feet of a lead gas-pipe. It is best to use both water and gas-pipes, so that, if one be under repair, the other shall complete the circuit: a well-soldered connection should always be made.

A deep, narrow trench filled with coke, in which a copper plate, or what is better, a strip of lead, is buried, may sometimes be used, bearing in mind that the object is to expose as large a surface as possible.

Plates must always be buried *flat*, and not coiled into a cylinder or spiral, and upright rather than horizontal.

On connecting up a circuit of less than ten miles, it frequently happens that a permanent current appears on the instrument, arising from the earth-plates forming a battery. If an iron gas-pipe be used for an earth at one end, and a lead water-pipe or a buried plate of copper at the other, a current is always set up.

It is necessary, then, to be careful that both earths are as nearly as possible alike, and to change one or both till the current ceases.

PART III.

MAGNETISM AND ELECTRO-MAGNETISM.

99. PIECES of iron or steel which have long remained in a north and south position, or have been subjected to a certain mechanical and electrical processes, attain the power of attraction and repulsion, and are called *magnets*. Some of the ores of iron possess the same property, and are called *natural magnets*, or *loadstones*.

100. If a magnet be balanced on a pivot, so as to be free to move horizontally, as in the mariner's compass, it will place itself in the *magnetic meridian*; that is, point *north and south*. The end which points to the north is called the *north pole*; that which points to the south, the *south pole*. The force which causes it to point north or south is called its *directive force*.

If a steel bar be balanced on a horizontal axis, so that it may move freely in a vertical plane, it will remain at rest in any position. Magnetize it, and the north end will appear to have become heavier, or will *dip*, unless it be placed east and west, when the magnetic force will simply produce pressure on the pivot;

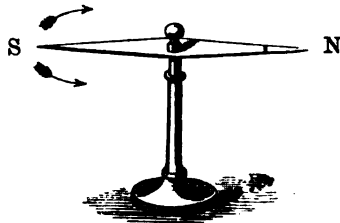


FIG. 11.

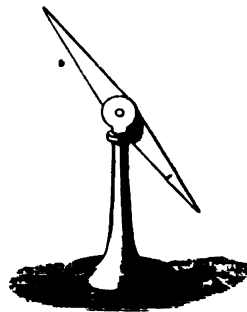


FIG 12.

for the manner in which it is pivoted prevents its moving when in this position.

The north pole is generally marked either by the letter N, or by a file-cut, as in the figure, and is sometimes called the *marked*, while the other is called the *unmarked* pole of the magnet. It is also sometimes called the *negative*, the other being called the *positive* pole, and they are designated, as in electricity, by the signs — and +. There is no difficulty in recollecting which is which, because the N or — sign stands equally for negative or north.

101. When two magnets are brought near one another, the similar poles will be found to repel, the dissimilar poles to attract—that is, the north pole of one will repel the north pole and attract the south pole of the other, and *vice versa*. But if a piece of iron or *unmagnetized* steel-bar be used, either pole will be attracted, and no repulsion whatever will occur.

Bodies attracted by a magnet, themselves attract the magnet with equal force.

MAGNETIC INDUCTION.

102. Magnetism acts by *induction* at a distance through all substances not themselves capable of being magnetized. A compass in a brass or wood box is as easily affected as if it were not so enclosed; but if shut in an iron box, a magnet outside would act on it indirectly only and feebly, through the magnetism induced in the iron of which the box is composed.

The immediate neighbourhood of a magnet is called the *magnetic field*, and pieces of iron or steel, magnetized or unmagnetized, brought into this field, acquire magnetic power by induction. Hence, if a small or weak magnet is used to test the polarity of a stronger one, it is necessary to keep it at a distance; for when brought too near, the superior power of the stronger overpowers the polarity of the weaker for the time being, and attracts either pole indifferently. Hence, if it be desired to find whether a pole be N or S, ascertain by which pole it will be *repelled*.

The attraction of two dissimilar poles is greater than the repulsion of two similar ones. In attraction, each tends to develop in the other a magnetism opposite to its own, and similar to that of the other, and thus strengthen each other. In repulsion the opposite effect takes place.

The magnet acts upon iron by inducing an opposite polarity in the part nearest to itself, and in consequence the two dissimilar poles attract each other, so that the iron will adhere to the magnet when placed in contact with it. The opposite extremity of the piece of iron exhibits the same polarity as that of the magnet itself, and will attract a second piece of iron (Fig. 13).

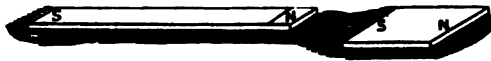


FIG. 13.

Nearly all traces of magnetism in the iron cease as soon as it is removed from the influence or *field* of the magnet, for *iron* cannot retain magnetism, or cannot be permanently magnetized, when soft and pure. When hard or impure, it retains a certain amount of polarity, which is called *residual magnetism*.

Steel, on the other hand, is not attracted as forcibly as iron; it acquires magnetism with greater difficulty, but retains it more or less permanently. The harder the steel, and the longer the bar, the more permanently will it retain its magnetism.

103. The inductive force of a magnet upon soft iron varies inversely as the distance between them, while the action of one magnet upon another varies as the square of the distance, so long as they are so placed that the two adjoining poles act upon each other free from the interference of the remaining poles.

104. If a magnetic bar be tested, it will be found that its force appears to reside very near the ends or *poles*, and that it decreases to nothing at the centre of the length of the bar. If a magnet be broken into any number of pieces, each piece will become a perfect magnet; but if the pieces are placed closely together again, the intermediate poles will disappear, and the magnet will have only two poles, as at first. The magnetism, however, is really distributed throughout its mass.

105. A straight bar is called a bar-magnet; the small bar magnets used in telegraph instruments and ships' compasses are called *needles*; and when a bar is bent, so as to bring its two ends or *poles* near one another, it is called a *horse-shoe* magnet.

A *compound* magnet consists of two or more bar or horse-shoe magnets placed side by side, with their similar poles in contact. Care must be taken that all the bars are equal in power, or the feebler will be weakened, or even reversed, by the stronger.

The advantage of forming a magnet of several thin bars instead of a single thick one is, that the thinner bars are more easily magnetized. But if two bars equal in power be placed together, the combination will not have double the strength of the single bar, but only about half as much again. This is because of the reaction of the similar poles upon one another.

106. The processes for magnetizing steel bars, or forming artificial magnets, are founded on the principle that a north pole induces a south pole, and *vice versa*.

A magnet can only be charged to a certain maximum, called the *point of saturation*; and this point is generally ascertained by the weight which the magnet is capable of bearing. The small magnets employed in needle telegraphs should be capable of bearing their own weight together with that of the axle.

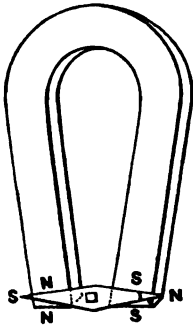


FIG. 14.

To magnetize a small bar such as the *needle* of a telegraph instrument, all that is necessary is to lay it across the poles of a horse-shoe magnet, the end required to be the north pole on the south pole of the horse-shoe, and *vice versa* (Fig. 14);

rubbing them together once or twice in the direction of the needle's length.

To magnetize a pair of bars of several inches in length, place them flat on a table, as in Fig. 15, between two pieces of soft iron, as armatures. Place the horse-shoe magnet S N on one end of either of the bars, with its *north* pole upon that extremity of the bar which is required to become a *south* pole. Slide the horse-shoe along the bar, carrying it round the whole system

several times, stopping finally in the centre of one of the bars, as shown in the figure. Repeat the process on the other face of the bars.

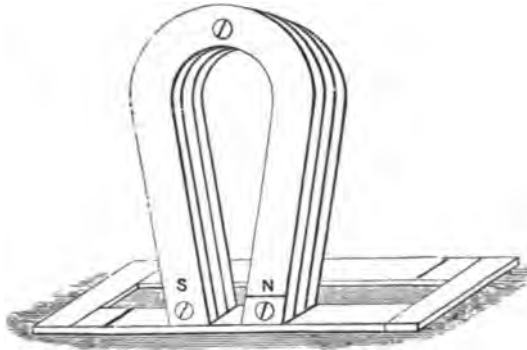


FIG. 15.

A horse-shoe may be magnetized in a similar manner, commencing at one end of the poles, sliding the magnet round the horse-shoe and its armature, finally stopping at the centre of the curve of the horse-shoe (Fig. 16).

When a bar is carelessly magnetized, it may acquire one pole or more in addition to those at its ends, and will be found not to act as strongly as it should do.

107. If the north pole of a weak magnet be applied to the north pole of a stronger magnet, the polarity of the weaker magnet will first be destroyed (the bar will be *demagnetized*) and then *reversed*, the north pole becoming a south pole.

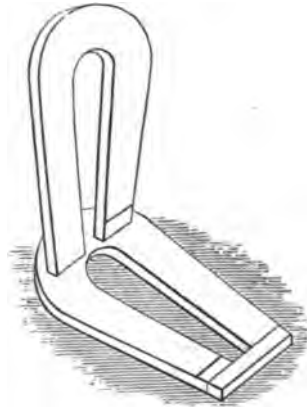


FIG. 16.

The earth itself is an enormous magnet, and objects upon its surface are constantly in its *field*, and subject to its influence; consequently, if magnetized bars are laid aside without regard to the direction in which their poles are placed, they become *demagnetized* by its action.

To prevent this loss of power, *armatures* or *keepers* of soft iron are used, applied to or placed across the poles. When out of use, bar magnets should be placed as in Fig. 17, where A A are the armatures, and S N N S the magnets. The armatures become magnetized by induction, and in their turn induce magnetism



FIG. 17.

in the bars. This mutual induction is more powerful than the inductive influence of the earth.

When several pieces of iron are hung from one of the poles of a permanent magnet, each one develops magnetism in the piece next to it, and its own magnetism is increased thereby.

Hence the lifting power of a magnet may be increased by hanging to it, from time to time, additional pieces of iron.

108. The armature of a horse-shoe magnet will support a greater weight than would be carried by the two poles, because of the mutual inductive reaction between a magnet and its armature.

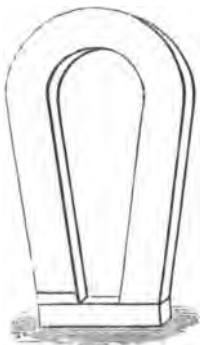


FIG. 18.

The armatures of horse-shoe magnets are applied as in Fig. 18. They may with advantage be weighted, and if the weight is gradually increased, taking care never to make it sufficient to tear the keeper away (which would weaken the magnet),

the strength of the magnet will be increased also.

The armature should always be slid off, never forcibly detached.

The poles which attract each other tend to preserve each other's magnetism; those which repel tend to destroy it.

109. Needles free to move horizontally, as compass-needles, always take up the position most favourable for retaining their

power. This may seem to contradict what has been before said (100), since the north pole of the needle turns towards the north pole of the earth. But the north pole of the needle has really an *opposite* magnetism to that of the north pole of the earth, and strictly should be called the *south* pole, as in French works.

110. Magnets required to be set in motion by a slight force, as in telegraphs, must necessarily be short. They therefore lose their power readily, and are easily demagnetized by lightning, or even reversed. There is an advantage in making the moveable parts of soft iron, and pivoting them upon large permanent fixed magnets, so that they may be magnetized by *induction* (102). Large magnets retain their power for a long time.

Cast steel is best suited for permanent magnets: it may be tempered by being heated to a cherry-red in a tube, to prevent burning, and immersed in water.

111. The relative strength of horizontal needles may be measured by an observation of the time occupied by them in performing a fixed number of vibrations. They obey the laws of the pendulum, and the forces acting on them are *inversely* as the squares of the times of vibration; for the stronger their magnetization, the greater will be the effect of the directive force of the earth upon them, and the faster will they vibrate. Thus, if the needle A make twenty vibrations in ten seconds, and B the same number in five seconds—that is, in half the time—then, as $A : B :: 5^2 : 10^2$, or as 25 to 100, B is four times as powerful a magnet as A.

ELECTRO-MAGNETISM.

112. A wire through which a current is flowing possesses, for the time, properties similar in some respects to those of a magnet. It attracts iron-filings, and attracts or repels other wires through which currents are flowing, but it has no effect upon light bodies which would not be attracted by the magnet.

113. Two parallel conducting wires will attract each other if the currents flow in the same direction in both, and repel if they flow in opposite directions (Fig. 19).

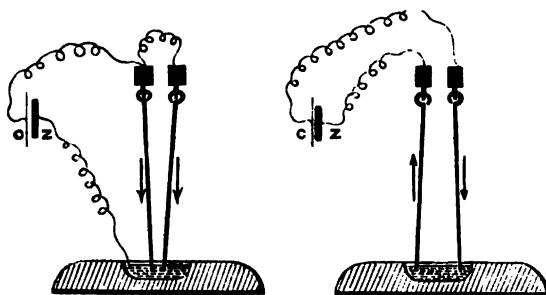


FIG. 19.

114. A conducting wire is in like manner attracted and repelled by a magnet, but in both cases the force is not simply one of attraction or repulsion, but one which would cause the wires, or the wire and magnet, to revolve round each other, when so fixed or pivoted, as to be able to move freely in all directions.

Let M be *one pole* of a magnet, and w a section or slice of a conducting wire; if w is fixed and M free to move in all directions, M will revolve round w Fig. (20). But the *other pole* of the magnet M would

tend to revolve in the *opposite* direction round the wire, so that in order to produce the *revolution* of a conducting wire around a magnet or of a magnet, around a conducting wire,



FIG. 20.

they must be arranged so that the current acts upon one pole only of the magnet (Fig. 21).

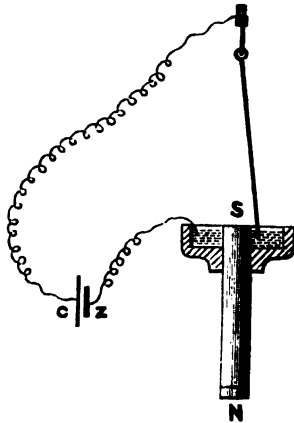


FIG. 21.

115. If the magnet N S be fixed on an axis, as shown in Fig. 22, the tendency of its two poles to rotate in opposite directions round the current flowing in the wire will cause it to

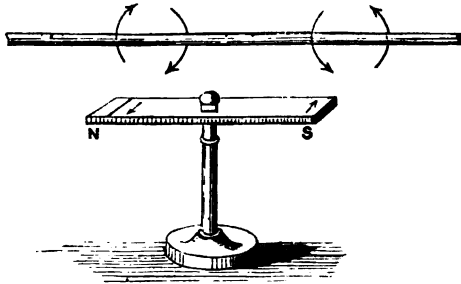


FIG. 22.

take up a position at right angles to the wire. For, as the two poles N S tend, when considered separately, to revolve round the wire in the direction shown by the arrows, the end N will be urged *towards*, and S *from* the reader; but as the needle is pivoted upon a vertical point, it is capable of motion in the horizontal direction only.

116. The following illustration, contrived by Ampère, is useful as an aid in determining in what direction a current will move a magnet. .

Suppose one's feet to be connected to the copper, and one's head to the zinc pole of a battery, the current would flow upwards through the body. If a magnetized needle suspended vertically, as in a needle instrument, be held before the breast, the north pole of that needle would be moved to the left hand, towards a position at right angles to the body. If the needle were held at the back, or if the direction of the current were reversed, the direction in which the needle would be moved would also be reversed.

In these diagrams the body of the person holding the needle is represented by the wire Z C, and the needle by S N.

The wire in front of the needle.

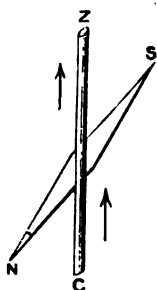


FIG. 23.

The wire in front of the needle, and the current reversed.

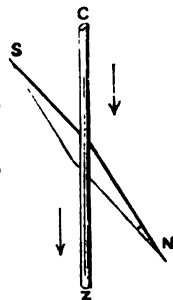


FIG. 24.

The wire behind the needle.

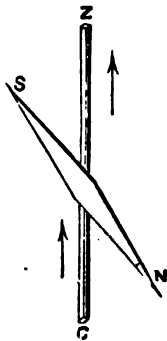


FIG. 25.

The wire behind the needle, and the current reversed.

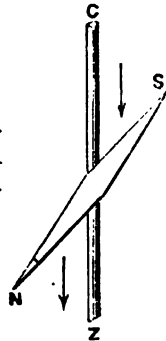


FIG. 26.

It will be perceived that, when the wire is bent round the needle thus (Fig. 27), its two halves act similarly on the needle, and the effect is doubled. The current ascends *behind* the needle, as in Fig. 25, and descends *in front* of it, as in Fig. 24.

If the wire be bent a second time in the same direction round the needle, the effect will be again doubled; and by a still further increase in the number of turns a corresponding increase in force will be obtained.

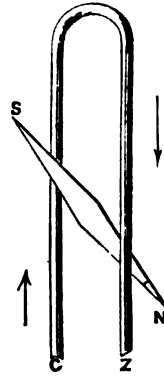


FIG. 27.

117. If the wire is covered with an insulator, as silk or cotton, so as to compel the current to traverse its entire length, and is formed into a circular coil, or wound upon a frame, it may be so arranged as to make several hundred, or even thousand, turns around a magnet pivoted within it, and will move even with a very feeble current. This arrangement is called a *galvanometer*, or current measurer (120). The angle or number of degrees through which the magnet or *needle* is moved shows the *quantity* of electricity passing through the coils. The *direction* in which the needle is moved shows the *direction* in which the current is flowing.

118. A conducting wire, if straight, possesses no directive force, but when bent to form a loop or ring, so that the parts

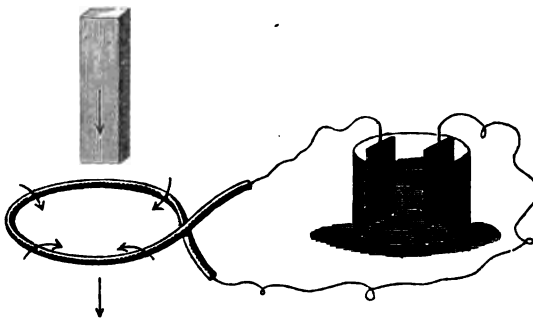


FIG. 28.

which cross one another do not touch (Fig. 28), if one pole of a magnet be presented to the centre of the ring, the tendency

to rotate will cause the magnet to be drawn into or expelled from the ring, according to the direction of the force of rotation. It will therefore appear to be attracted or repelled by the magnet. If properly suspended, the ring will be found to possess directive force or polarity, and will place itself north and south, the *edges* of the ring standing east and west. The effect is multiplied if the ring be formed of a number of turns.

119. If the wire be formed into a *helix*, or spiral, its polarity will be more decided, and it will behave precisely like a magnet.

If the spiral be wound so that the current flows from *right* to *left* (Fig. 29), that end of the wire which is connected to the +



FIG. 29.

or copper pole of the battery will be a north pole. If, on the contrary, it be wound like an ordinary screw, so that the



FIG. 30.

current flows from *left* to *right* (Fig. 30), the + end of the wire will be a south pole.

The directive force of a helix is very clearly apparent in the apparatus shown in Fig. 31.

The conducting wire coiled as a spiral is connected to a voltaic pair, and arranged by means of a cork, so as to float in a vessel of acidulated water.

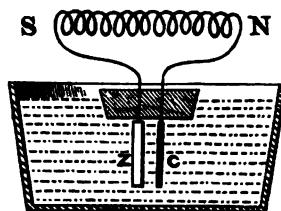


FIG. 31.

GALVANOMETERS.

120. There are two classes of galvanometers: one sometimes called a "*detector*,"¹ in which the needle hangs vertically, and is kept in place by the weight of its lower end (Fig. 32), and one in which the needle is poised on a point, like a mariner's compass (Fig. 33), or suspended by thread.

The vertical galvanometer needs no adjustment, the north end of the inner needle being made sufficiently heavy to keep it upright. Its sensitiveness may be considerably increased by lessening the weight of the lower or north end of the inner needle; but in this case the instrument must be so placed that its dial faces the north or south, or the *dip* (100) will cause the needle to hang on one side. Whenever the needle of a needle instrument (which is simply a vertical galvanometer with a reversing key), will not hang vertically, except the case is in

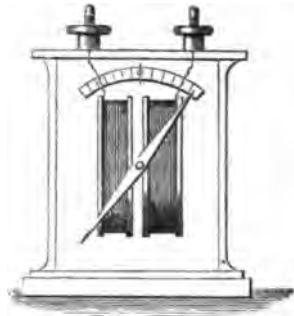


FIG. 32.

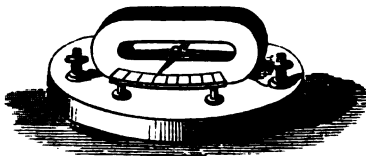


FIG. 33.

one particular position, it is because of the dip. Needles properly balanced for this country will be found wrong if sent to Australia, for there the south end will dip, or appear the heavier.

The horizontal galvanometer is much more sensitive than the vertical, because the friction of the pivot is less, and because it is not necessary to weight the needle. However, as its needle is kept in position by the directive action of the earth only—that is, by the tendency of a magnetized needle to stand north and

¹ The detector may with greater propriety be called a *galvanoscope*, as its principal use is to show the *presence* of a current, not to measure it.

south—the case of the horizontal galvanometer must be turned so as to bring the coils into their proper position, and the needle to the zero of the scale, and must be levelled so that the pivots may move freely. An ordinary detector, when laid on its back and levelled, will be much more sensitive than when upright.

The use of a very freely-suspended horizontal needle would be extremely tedious, were it not easy to check its swinging by making and breaking battery-contact in such a manner that the current shall oppose instead of aiding its motion. The application of a feeble magnet, such as a penknife, will produce the same result.

121. As the needle of a *vertical* galvanometer is kept in its place by the weight of its lower end, which is always the same, and as the force with which a current acts upon it depends on the strength of its magnetism, which is constantly decreasing, its indications vary from time to time. But in a *horizontal* galvanometer, as the needle is kept in its place solely by its tendency to point north and south, the feebler its magnetism the less effect will the directive force of the earth have upon it, and the less resistance will it offer to being moved by the current; while, on the other hand, the current acts with diminishing force as the magnetism decreases. The two forces thus counteract one another, and the instrument is *constant*.

122. In neither of these instruments is the graduation into degrees, or equal parts, correct when the deflection exceeds 20° ; for the further the needle moves from a position parallel to the wires of the coil, the more nearly does it approach a right angle, where the effect is null; so that the action of the current upon it becomes less and less powerful as the deviation or deflection increases.

In a well-made vertical detector, the value of the degrees marked on the dial were found to be *nearly* correct to 30° , and

40° were equal to 44 parts of electricity.

50°	"	65	"
55°	"	78	"
60°	"	93	"
65°	"	130	"

But the value of the ordinary degrees would not be alike for any two galvanometers; each must be *calibrated* or graduated by actual trial, or by comparison with a standard instrument.

The following is one method of *calibrating* a galvanometer:—

(1.) Find the resistance of the galvanometer and of the battery employed, and, by means of a rheostat or set of resistance coils (78), adjust the resistance of the circuit till the needle marks 10° on the scale.

(2.) Halve the *total* resistance of the circuit; the force acting on the needle will now be doubled. Mark the deflection, and call it 20° .

(3.) Again halve the resistance; the force of the current will once more be doubled, and the deflection may be marked as 40° ; and so on.

Suppose the battery resistance be . . .	10 ohms.
That of the detector	200 „
And the resistance added to reduce the de- flection to 10°	790 „

The total resistance will be . . . 1000

To double the force acting on the needle, one-half 1000, or 500 ohms, must be removed from the circuit.

When the resistance of the detector and rheostat is very much greater than that of the battery (as, for instance, when one large cell is used), the battery resistance may be disregarded.

The method of finding the resistance of the battery and galvanometer will be described hereafter.

123. In the *sine* galvanometer, these errors of graduation are avoided. The needle is pivoted horizontally, and the coils are made movable, so as to *follow the needle* as it is deflected; the needle is by this means constantly kept parallel to the wire; and the current always has the same amount of leverage upon it. The instrument is placed so that the needle points north and south, and stands at the zero of the graduation. The coils are now placed in circuit, and turned in the direction in which the

needle is deflected, so as to follow its motion until the directive force of the needle is exactly balanced by the force of the current, and the needle again points to the zero of the graduation. The forces measured by this instrument are proportionate to the *sine* of the angle through which the coil has been moved, not to the angle itself.

The sine of any number of degrees is that part of the diameter of a circle which is included between a line drawn from its centre to the zero point of the graduation G O (Fig. 34), and

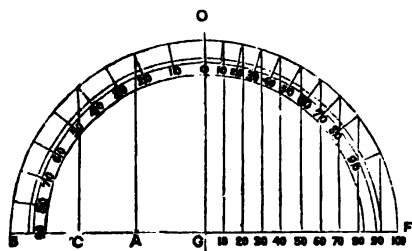


FIG. 34.

another line parallel to the first, cutting the circle at the degree whose sine is required: thus G A is the sine of 20° , and G C is the sine of 40° . Sines increase in a different ratio to the degrees they represent, the diagram shows that the sine of the second 20° is less than the sine of the first 20° ; A C is less than G A.

In using the sine galvanometer it has been usual to read off the angle through which the coil is moved, in *degrees*, and to find the sine by a reference to a table of sines. For ordinary purposes, it is more convenient to graduate the instrument with a scale of sines, which may be constructed thus:

Divide the radius G F into 100 equal parts, from which draw lines at right angles, and mark the points at which they cut the circle. The comparative strength of currents, when read off a scale so formed, will correspond with the results which would be obtained if the deflection of the needle were read off in degrees, and reference made to the printed tables for the corresponding sines. A table of sines is given at the end of the volume.

It will be evident that the sensitiveness of this galvanometer increases with the angle which the coils make with the magnetic meridian, because the *directive* force of the needle is decreased, while its *magnetism* remains the same. It follows from this that the length of the divisions of the circle which indicate equal forces increase as the deflection approaches a right angle.

The right-hand quadrant of the diagram is graduated to a scale of sines, the left to a scale of degrees. The sine of 90° is equal to radius, and in a table of sines it is made equal to 1,000. If, then, the radius CR had been divided into 1,000 equal parts, and the corresponding divisions set off on the quadrant, the readings would have corresponded exactly with those of the table. But sufficient accuracy for our purpose is obtained by a division into 100 parts.

124. A horizontal galvanometer may be greatly increased in sensitiveness by making the outer needle, or pointer, a magnet; placing its poles in a contrary direction to those of the inner magnet (Fig. 35). If the two are exactly equal in power, the pair will have no tendency to point to the north, because the directive action of one will be counteracted by the equal and opposite action of the other; and the pair will be what is termed *astatic*. One needle should, in practice, be a little stronger than the other, so that the pair may have sufficient tendency to point north and south, to enable it to regain its position after having been deflected. The more nearly the two needles are alike in power, which may be known by the slowness of their vibration (111), the greater the delicacy of the galvanometer.

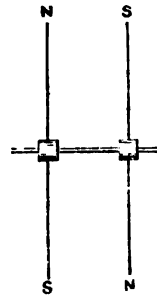


FIG. 35.

To obtain the greatest sensitiveness, the needles should be exactly alike, and should be magnetized together; any excess of magnetism may then be removed from the stronger of the pair by the similar pole of a needle of equal strength. The nearer to the centre the touch is made, the more delicate will be the effect produced.

But an astatic galvanometer is not constant, for the *relative*

force of magnetism in the two needles varies considerably from time to time.

125. By the use of a *directing magnet* to increase or diminish the intensity of the magnetic field, the sensitiveness of a horizontal galvanometer may be varied to a great extent, and rendered more or less astatic. The magnet should be of considerable power, and be placed upon a vertical rod passing through its centre, fixed above the coil immediately over the axis of the needle, in such a manner that the magnet can be turned horizontally, or be removed nearer to or further from the needle vertically.

If it is placed with its poles opposed to those of the needle, it will add its directive force to that of the earth, and, by holding the needle more powerfully in its position, will *lessen* its sensitiveness. The nearer the magnet is approached to the needle, the greater will be its power over it; and it can be arranged so as to hold the needle in any desired position.

But if it is placed in a reverse direction, so as to *repel* the needle instead of attracting it, it will lessen the directive force of the earth so as to increase the sensitiveness of the needle, and, in a certain position, will render the galvanometer astatic.

When the magnet is too near the needle, it repels it to the full extent of the scale; if it is raised upon the supporting rod, the repelling effect will decrease.

The greatest sensibility is obtained at the point at which the needle can be held to zero, but where the slightest lowering of the magnet upon the rod will again repel the needle to the full extent of its swing.

126. The directing magnet may be laid on the table in a line pointing north and south; after the compensation has nearly been effected it may be completed by a smaller magnet.

The degree of sensitiveness of the galvanometer may be ascertained by the method described at paragraph 111, for the more nearly a needle, or a pair of needles, is made to approach the astatic condition, the *slower will it vibrate*; and the *more powerfully it is directed*, or held in position, the *quicker will it vibrate*.

127. The *differential galvanometer* shows the *difference in strength of two currents*. It is wound with two wires, side by

side, so arranged as to be exactly equal in their effect on the needle. The wires are often formed into a kind of ribbon, by plaiting together the silk with which they are covered.

When, therefore, two equal currents are made to pass in opposite directions through the coils, they will exactly balance one another, and the needle will not move. If, however, one current be stronger than the other, the balance will be destroyed, and the needle will be moved by the stronger current, with a force equal to the difference in the strength of the two currents. And when the same current is made to pass through both coils, but in *opposite directions*, the needle will not move, however strong the current may be.

In making a differential galvanometer, it frequently happens that the two coils are not exactly equal in effect on the needle; and it is necessary to add a few turns to the weaker coil. But as the two coils must not differ in resistance, an equal quantity of wire must be added to the stronger coil, wound on a separate bobbin, half in one direction and half in an opposite direction, so that it may have no effect on the needle. Form the wire into a loop, and commence winding from the centre of the loop.

This instrument is used to measure resistances, by comparing them with the standard resistance coils, the principle being this: If the current from a battery be split or divided between two similar wires of unequal lengths, each connected to one of the coils, the greater part will pass through the shorter wire, overpower the effect of the weaker current in the other coil, and move the needle; if the shorter wire be now lengthened till it is equal to the longer one, the currents will be equal in both coils and the needle will again be immovable.

In order to be able to balance widely differing resistances, one coil of the galvanometer is provided with *shunts*, which reduce the effect of the current upon it, so that the 100 ohms of a set of resistance-coils connected with the shunted coil may be made to balance 1,000 or even 100,000 ohms' resistance connected with the other.

128. To produce a very sensitive galvanometer, the wire of the coil must lie as close to the needle as possible; the silk covering must be as thin as is consistent with safety from

contact, in order that the number of turns may be as great as possible within a given distance, and the needle must be freely suspended; if pivoted, the pivot should work in a jewel, and the insulation must be perfect.

Perfect insulation is especially necessary in a differential galvanometer, for leakage from one of the two parallel wires to the other is fatal to accuracy; and as they lie close side by side through their entire length, the tendency to leakage is very great.

The covered wire should be well baked, to dry it, taking care not to overheat it so as to injure the silk; and when being wound on the coil, it may be drawn through hot melted paraffin.¹ The finished coil may be dipped into paraffin. Shellac varnish is sometimes used instead of paraffin, but it is more difficult to apply. After each layer of the wire has been varnished, the coil should be baked, to drive off the liquid of the varnish, before another layer is put on. When this is not done, the whole coil will be more or less in contact, and it will be very difficult to get rid of the moisture.

129. The effect of the resistance of a circuit on the strength of a current must be considered. It will be seen, by what is shown in paragraphs 90 and 91, that a galvanometer of small resistance—that is, of a few turns of comparatively thick wire—is the most fit for testing short lengths of wire or small resistances, and that the greater the resistance to be tested, or the longer the circuit on which the galvanometer is used, the finer must be the wire, and the greater the number of turns (convolutions).

The resistance of the galvanometer forms part of the resistance of the *circuit*; if, then, an instrument of high resistance is placed in a circuit with a thick wire and a battery of large cells, it will, because of its resistance, reduce the strength of the current to a greater extent than the number of turns of the wire will multiply the effect of the current on the needle; but if the resistance to be tested is very large—as, for instance, that of the

¹ To prevent mistakes, it may be as well to say that what is sometimes called paraffin *wax*, not paraffin *oil*, is to be used. It must be very free from the acid which paraffin sometimes contains, or it will act on the wire and become green.

insulation of gutta-percha, several million ohms—a galvanometer resistance of even six or eight thousand ohms is almost insensible, while the multiplying power of such a galvanometer is very great, because of the number of convolutions.

Place a single cell, whose resistance is (say) 2 ohms, in circuit with a galvanometer of 10 turns of copper wire 65 mils diameter (No. 16). The resistance of this short wire will be almost nothing, and may be neglected; for a mile has a resistance of only 12.25 ohms. The total resistance of the circuit will therefore be 2 ohms; then $l = 0$, $r = 2$, $R(l + r) = 2$, and $E = 1$ (86), the strength of the current will be $\frac{E}{R} = \frac{1}{2}$, and the multiplying effect of the galvanometer being 10, the effect on the needle will be $\frac{10}{2} = 5$.

With 100 similar cells the electromotive force is 100 times as great, but the resistance will be increased in the same proportion. Therefore, as $\frac{100 E}{100 R} = \frac{E}{R}$, the strength of the current is plainly the same as before, while, as the multiplying effect of the coil is not altered, the effect on the needle is also the same.

Replace the short-coil galvanometer by one of 5,000 ohms' resistance, having (say) 1,000 turns of fine wire. With one cell, $l = 5000$, $r = 2$, $R = 5002$, and $E = 1$. The strength of the current is therefore $\frac{1}{5002}$, exceedingly feeble, so that, even when multiplied by the 1,000 turns, the effect on the needle will only be $\frac{1000}{5002}$ or about $\frac{1}{5}$ th of what it was with the short coil. But with 100 cells $r = 200$, $l = 5000$, $R(l + r) = 5200$, and $E = 100$: we have then $\frac{100}{5200} = \frac{1}{52}$ as the strength of the current; and for the effect on the galvanometer $\frac{1000}{52} = 20$, or fourfold what it was at first, although the strength of the current is twenty-six times less.¹ It has been supposed here that the effect of

¹ $\frac{1}{52}$ instead of $\frac{1}{5}$ of what the strength would have been were it not for the diminution caused by resistance.

all the turns of the wire upon the needle are precisely equal; this is, of course, not strictly true, but sufficiently so for the purposes of the argument.

For ordinary telegraphic purposes, the galvanometer for ascertaining the resistance and insulation of the line and instruments may be one with a horizontal needle $1\frac{1}{2}$ in. to 2 in. long, working in two jewelled pivots between the halves of a double coil, as in a needle instrument. The coils may be wound with wire, 4 mils (No. 40), to a resistance of 750 ohms each, or 1,500 for the pair. They will measure about $2\frac{1}{4}$ in. $\times$ $\frac{7}{8}$ in. $\times$ $\frac{1}{16}$ high. Such an instrument will give from a single cell a deflection of 43° , through a resistance of 100,000 ohms.

The detector for ascertaining if a current passes may have a vertical needle pivoted between two ordinary needle-instrument coils, the needle being an inch long. Four turns of wire 50 mils diameter (No. 18), wound *outside* the fine-wire coil, will (when used instead of the fine coil) give about 30° deflection with one cell of the ordinary Daniell battery described in paragraph 48, and will be very suitable for ascertaining its working condition. Such a coil will give about the same deflection with 1 cell as with 100. For batteries of large plates a single turn will suffice.

A fine wire galvanometer may, however, be *shunted*, so as to be used for testing batteries—nay, even a Thomson's reflector may be so reduced by shunting as to be employed. Here the resistance of the shunt will be so small that the current in the circuit will not be enfeebled; and though a very small portion passes through the galvanometer, the little which does pass is so multiplied by the great number of convolutions that it produces an effect on the needle.

When delicate galvanometers are disturbed by moving masses of iron, they may be enclosed in a sheet-iron case (102). It is often found desirable in a telegraph office to place them on an iron plate, to cut off the disturbing effect of the instruments.

129a. The *tangent* galvanometer consists of a ring having a groove on its edge filled with wire (Fig. 36). The needle is hung or pivoted precisely in the centre of the ring, and must

not be longer than one-sixth of its diameter—an inch-needle requiring at least a six-inch ring. The arrangement is as if a short compass-needle enclosed in its box were placed in the centre of the ring. The current is proportional to the *tangent* of the angle of deviation of the needle.

A *tangent* is a line drawn at right angles to one of the radii of a circle, and touching its circumference: *A B* and *B D* are tangents to the circle in Fig. 37. *B 1* on *A B* is the tangent of the angle of 20° ; *B 5* on *B D*, the tangent of 45° .

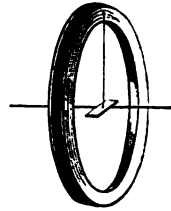


FIG. 36.

When a short needle *N S*, with a pointer attached to it at right angles, is suspended in the centre of a circular coil of wire

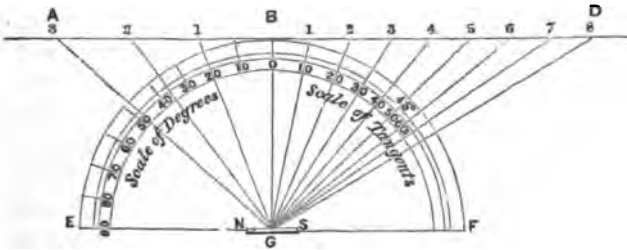


FIG. 37.

fixed perpendicularly to the dial *E B F*, and the apparatus is so placed that the coil shall exactly face east and west, if the needle is deflected by a given current to 20° , double the force will not deflect it a *second* 20° , but to *double the distance measured on the tangent A B*. Thus the equal divisions 1, 2, 3, on the line *A B*, represent equal forces; and if the pointer be long enough to reach *A B*, these divisions will serve as a scale.

As it would be inconvenient to read off from a straight line, the circle may be divided, sufficient accuracy for most purposes being obtained by drawing lines from the centre to each division on the line of tangents, marking where they cut the circle, as is shown at *B D* and *B F*.

In mathematical tables the tangent of 45° is 1.00, so that if the tangent of 45° is divided into 100 equal parts, and these set

off on the circle, the readings will correspond with those which would be obtained were the circle divided into *degrees*, and the table referred to for the corresponding tangents, the place of the decimal-point being duly considered. But, whatever be the number of the divisions of the line of tangents, the strength of currents measured will be proportional to the readings obtained.

As the divisions of the circle decrease in width as the angle of deflection increases, the greater the number of equal parts into which the straight line is divided the greater will be the accuracy of the divisions of the circle. In practice it is found convenient to divide the tangent of 45° into 50 parts, and to carry the same graduation to the extremity of the scale, as is shown in the diagram.

It is very convenient to place a piece of silvered glass at the bottom of the box which contains the needle, so that in taking an observation, the needle and its reflection in the mirror are made to coincide, the eye is then immediately over the needle, and the error which frequently arises from a wrong position of the eye is prevented. This plan is a good one for all galvanometers.

Although, because of the distance between the coil and the needle, this instrument is not so sensitive as other galvanometers, it is extremely useful for testing overground wires, because of the length of its scale and its accuracy. The wire should be comparatively thick, so that, with a given resistance, a large number of convolutions may be obtained; for the coil is so far from the needle, that the slight weakening of effect consequent on the increase of distance caused by the extra thickness of the wire, is far more than compensated by the increase of power arising from the additional number of turns which may be wound on without sensibly adding to the resistance.

A convenient form of tangent galvanometer has an inch needle, and a 6-inch ring wound with two equal coils each of about 25 ohms' resistance. The wire may be 8 (No. 35), or 14 mils (No. 30). A third of coil 5 mils (No. 18) may be wound over the two others, and will be useful for battery-testing. One cell should give 13 divisions through the thick-wire coil.

The two coils of finer wire may be used either singly or in series, so as to keep the deflection within the limit of the scale.

The needle is pivoted in a circular box, like a mariner's compass, and has a mirror below the needle for accuracy in reading off. Such an instrument is well suited for the daily tests of working circuits. A more accurate instrument may be made with two separate rings, each set at a distance of one-fourth its diameter from the pivot of the needle, one on each side the needle, instead of directly over it as in the form first described.

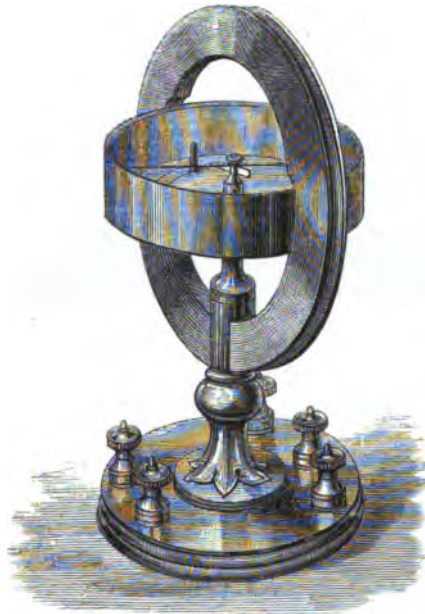


FIG. 38.

129b. *Gauguin's Tangent Multiplier* is thus described by Gavaret:—If a magnetized needle is submitted to the action of a circular current placed in the magnetic meridian, the tangents of the angles of the deviation of the needle will be nearly proportional to the force of the current, when the centre of the needle occupies the summit of a cone, having for the centre of its base the centre of the circular current, and when the height of the cone is equal to one-fourth of the diameter of its base. This

theorem is correct within $\frac{1}{1300}$, when the needle is from 1·17 in. to 1·36 in. in length, and the coil (or circular current) not less in diameter than thrice the length of the needle.

The wire of the coil may be wrapped upon the surface of a cone, or section of a cone fulfilling these conditions, till sufficient breadth is obtained to give the desired sensitiveness. The accuracy of the instrument is not lessened by wrapping several layers of wire one over the other.

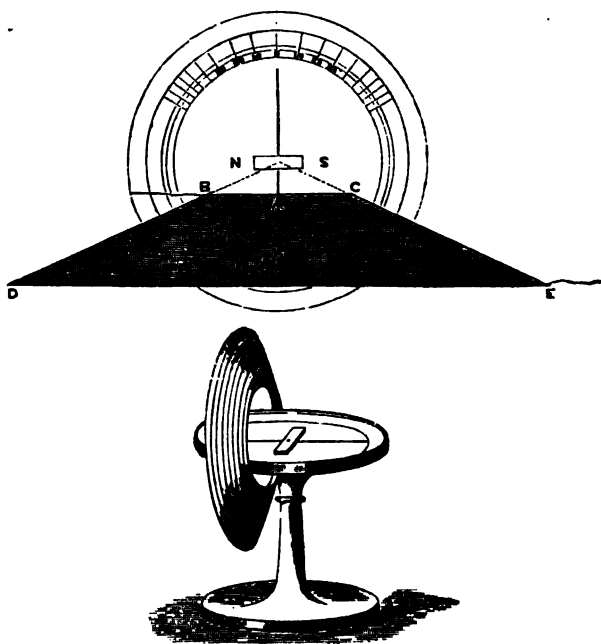


FIG. 39.

When the needle is 1 in. long, the nearest wire, B C, of the circular coil must be placed $\frac{3}{4}$ in. from the centre of the needle N S, and its diameter, B C, must be 3 in.

The angle of the conical coil-frame D B C E, is found by drawing straight lines from the centre of the needle, through the points B and C. The position of the needle-pivot must be accurately at the summit of the cone. The error arising from

defect in this respect may be compensated by placing a second coil similar to the first on the opposite side of the pivot.

129c. THOMSON'S REFLECTING GALVANOMETER has circular coils, in the centre of which a very light mirror, on the back of which are fixed four very small magnets, $\frac{1}{4}$ -inch long, one above the other, is suspended by a silk thread. A scale of equal parts is placed two or three feet from the mirror; a narrow slit is cut in the centre of the scale to allow a ray of light to shine upon the mirror from a lamp placed behind it. This ray is reflected back upon the scale, and is the index of the galvanometer; the angle through which the ray moves is double that traversed by the mirror, and it is therefore really equivalent to an index four or six feet in length, *without weight*. When the scale is three feet from the mirror, each degree of deflection moves the spot of light more than an inch. The great length of the index thus renders the slightest movement of the mirror perceptible; and as its deviation never exceeds 10° , the divisions of the scale accurately represent the force of the current. It is not only a most accurate, but a most convenient instrument.

This instrument is generally made astatic. There are two circular coils fixed one above the other; the two sets of magnets are connected by a strip of aluminium or a straw. It is often wound with German-silver wire, in order that its resistance may be little affected by changes of temperature, the additional resistance of German-silver over copper not being of importance, inasmuch as the instrument is intended to measure very high resistances.

The resistance of a Thomson with German-silver coils is sometimes as great as 50,000 ohms, and such an instrument will give, with a single cell of Daniell, a deflection of 200 divisions, through an additional resistance of 10 megohms (ten million ohms).

130. *Electro-magnets*.—It has been shown (112) that a wire spiral conveying a current has for the time the properties of a magnet. When such a spiral is wound on a bar of soft iron, the iron becomes magnetized for the time by its action, and its force is added to that of the coil. Thus, the force of the coil and iron together is very much greater than that of the coil without the

iron. This combination is called an *electro-magnet*, and its polarity depends upon the direction in which its coil is wound, as is shown in Figs. 29 and 30.

The electro-magnet has all the properties of a permanent magnet (a magnet made of tempered steel), so long as the current continues to flow: and it can be so constructed as to possess much greater power than it is possible to give to a permanent magnet.

If the iron be very soft and pure, it loses its magnetism immediately the current ceases; but if impure, or if hardened by hammering or turning, it retains a certain amount of *residual* magnetism, especially when it has been acted on by a powerful current, or if the armature has been allowed to touch the core. To prevent this, when the iron core for the electro-magnet has been formed, it should be made red-hot, and very carefully annealed by the fire being allowed to die out. The ends or pole-pieces of the core are sometimes bent or enlarged beyond the diameter of the core itself: there is an advantage in forging them in one straight piece, and filing them into shape, so that the fibre of the iron may be continuous and *in the same straight line*.

131. Electro-magnets are generally made in the horse-shoe form: that is, two bobbins are formed by fixing ivory or brass ends upon cores of the purest and softest iron; these bobbins are filled with covered wire, and fixed upon a connecting bar of iron. They are fitted with *armatures* of soft iron in the same manner as permanent magnets (Fig. 40). In winding and in connecting the two halves of the electro-magnet, care must be taken that the turns are all



FIG. 40.

in the same direction. The right direction can easily be found if the two bobbins be considered as parts of a straight magnet bent in the middle. Place the two bottom ends together in a straight line, and wind continuously onward.

If a wire is wound upon a metallic bobbin into which the cores are made to slip, the bobbin must be slit from end to end,

to prevent the circulation of the current induced in it by the magnetization of the iron; for this current would prevent its gaining or losing its power as quickly as it would otherwise do, and thus interfere with the rapidity of its action. If the coil is covered with a metallic tube, as is sometimes the case, the tube must be slit. There is an advantage in cutting a groove or slot about $\frac{1}{10}$ inch deep and wide lengthwise in the iron core, for the demagnetization of the core is retarded by the circulation of a current induced on its surface, which the slot to some extent prevents.

132. In electro-magnets and galvanometers, the effect of a current is multiplied by the number of turns of wire in the coil.

It is lessened by an increase in the distance between the wire and the core, each turn acting less powerfully than the one beneath it. The wire, therefore, if wound on the core itself, will act with the greatest force.

The laws which affect the galvanometer (129) apply equally to the electro-magnet. The current itself is enfeebled by each addition to the length of the coil, because of its increased *resistance* (78); and this will be more felt when the coil is placed on a short circuit than when the line-wire has itself considerable resistance; because, in the first case, a slight addition to the resistance of the coil bears a large proportion to the total resistance of the circuit; while in the latter case the proportion would be but small.

When a line-wire is very long, the current will necessarily be feeble, and the coil should consist of *fine* wire, which occupies little space, and allows very many layers to be wound on without increasing the distance from the core too much; while its resistance bears too small a proportion to that of the rest of the circuit to reduce the strength of the current materially.

But when the line is short, each layer of fine wire would decrease the useful effect by adding to the resistance of the circuit, more than would be made up by the multiplying effect of the increased number of turns; for a few layers would double the resistance of the circuit; while a thicker wire would not materially enfeeble the current, and though the distance of each

layer from the core rapidly increases because of the thickness of the wire, yet a sufficient number of turns may be employed without exceeding the distance at which the current acts with advantage.

132*a*. The maximum power is obtained when the resistance of the coil is equal to that of the line and battery. This law may be acted upon for short lengths of line; in long lengths, other elements enter into the calculation, as will be explained in the chapter on Insulation. For a *local* telegraph circuit, a short coil, and a few cells of battery are all that is necessary; but there is sometimes an advantage in being able to use the same description of cell both for the line and the local circuit: to effect this, the electro-magnet may be wound with about 7,000 convolutions of 14 mils (No. 30) wire, to a resistance of about 140 ohms, the core of each half of the electro-magnet being $2\frac{1}{2}$ inches long by $\frac{1}{2}$ diameter. Where the coil is acted upon by the current from the line itself, cores of the same dimensions are wound with about 12,000 turns of 8 mils (No. 35), to a resistance of about 500 ohms.

133. In winding galvanometers and electro-magnets, great care must be taken to preserve the insulation of the several turns of the wire, and especially to prevent metal filings from sticking to the covering, for they will pierce the silk and connect one turn with another, forming a "short circuit."

If a disc is fixed in the centre of the coil, and the coil wound from this disc as a starting-point in each division, both ends of the wire will end outside, and remedy the inconvenience so often arising when the inner end of the wire breaks.

134. In electro-magnets, wound evenly over their entire length, the magnetism increases as the square root of the length; or, if alike in all other respects, their power is proportional to the square root of the diameter of the core.

In four magnets, wound proportionally, 2, 4, 8, and 16 inches long, and respectively $\frac{1}{2}$, $\frac{1}{4}$, 1, and 2 inches in diameter, placed at distances of 6, 12, 24, and 48 inches, the attractive force will be the same.¹

¹ Dub.: as quoted in *Les Mondes*.

135. A hollow core is less powerful than a solid one; but if its ends are made solid, there is no great difference. The poles of an electro-magnet should, therefore, never be smaller than the core.

136. The attraction between the electro-magnet and its armature decreases as the distance between them increases; or, in other words, the attraction is inversely as the distance. When the armature is very near the core, the attraction diminishes as the simple distance, afterwards as the square of the distance.

The diminution of the effect of the current by increase of the distance of the wire is not so great when the diameter of the coil is small compared with its length; so that a long electro-magnet is comparatively more effective than a short one, with a given length of wire.

137. Iron will not take its full magnetism instantaneously, so that when the connection with the battery is made and broken rapidly, the core has not time to be *saturated*, and its attractive force will be but feeble. The act of demagnetization, or of losing magnetism, also takes time, but is effected more quickly than magnetization. The greater the tension of the battery, the more rapid the magnetization.

Thus, when very rapid action is required, even on short circuit, a considerable number of cells must be employed.

PART IV.

INDUCTION.

STATIC INDUCTION.

138. IN addition to the power of communicating a *charge* of electricity by spark or contact, an electrified body exerts an influence on all conducting bodies in its neighbourhood, even if it has not been made to touch them, causing them to exhibit signs of electricity, which increase if they are made to approach, and diminish if they are removed from the electrified body.

139. For instance, if an excited glass tube is made to approach the electroscope, the leaves will diverge; if the tube is removed, the divergence will decrease; and after the tube has been removed to a distance, dependent on the degree to which it is excited, the divergence will disappear altogether.

140. This influence on conductors not in contact is called *electrostatic*, or *static* induction. It is an analogous action to that exerted by the magnet upon pieces of iron in its immediate neighbourhood, and is most readily explained by the so-called double-fluid theory.

All bodies in nature are supposed to contain equal and opposite quantities of + and - electricity in a combined or neutral state. When an electrified body is brought sufficiently near an insulated unelectrified conductor, the neutral condition of the latter is disturbed, the two electricities are separated, the electricity of the *same* name (positive or negative) being repelled, and that of the opposite name being attracted; so that one part of the conductor is occupied by positive, and the other by negative, electricity; and, however thin the body may be, even if as thin

as a piece of gold leaf, its opposite sides may have contrary electricities.

141. Take two insulated plates of metal, A and B; connect each to a separate electroscope (2); charge A, its electroscope will diverge; bring it near B, taking care that spark be not allowed to pass between them, so as to charge B in the ordinary way; the electroscope connected with A will remain divergent, because the plate remains charged, and that of B will diverge, because of the induction exercised upon B by A (Fig. 41).

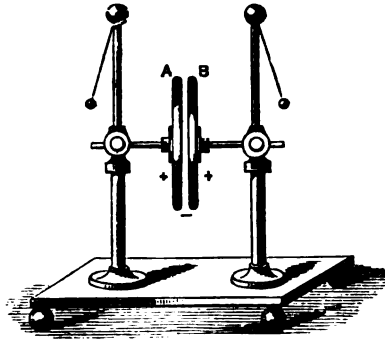


FIG. 41.

Separate the plates; A will remain divergent, but B will cease to show signs of electricity, because the inductive influence of A has ceased by its removal (Fig. 42).

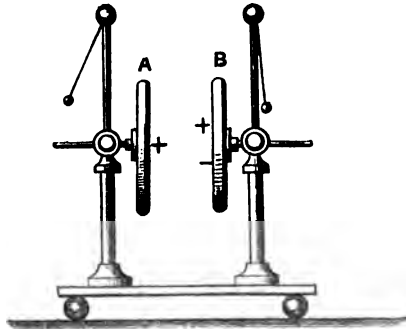


FIG. 42.

The cause is this. If the plate A is electrified positively, and made to approach the insulated unelectrified plate B, its positive electricity attracts the negative of B to the side facing A, and repels the positive to the other side of the plate. When A is removed, the two separated electricities of B re-combine, and it regains the neutral unelectrified state, while A has neither gained nor lost anything by its action on B.

Induction takes place only when the two plates differ in potential; if they are both electrified alike, there will be no induction between them, however powerful their charge may be.

Faraday constructed an insulated room, and electrified it strongly, but it was not possible to obtain the ordinary attractions and repulsions within it. Nor would a current flow from one conductor to another, when brought into contact, if both were equally charged, however strongly.

If, when the two plates are near each other, we touch A, we shall discharge it, and all electrical signs will cease in B also; for, the inductive action of A upon B having ceased, the two separated electricities of B re-combine, and its neutral condition is restored.

If we touch B, while under the influence of A, we shall remove from the former so much of the *positive* portion of its natural electricity as has been repelled and separated by the inductive action of A.

But B will retain all its *negative* electricity, because it is attracted by the positive electricity of A, and the electrical state of B is for the time held in abeyance by that of A. The electroscope of B will cease to diverge, because the opposite electricities of A and B expend their forces in attracting one another, leaving no force to be exerted upon the electroscope nor upon the finger; hence B cannot now be discharged. The electroscope of A would for the same reasons entirely cease to diverge, except that the charge of this, the *inducing* plate, is slightly greater than that which it has *induced* upon B, because a portion of it is expended in inducing a charge upon surrounding objects. Hence electroscope A remains slightly divergent.

Again, if we now touch A, we shall not discharge it, because of the inductive influence of B. In fact, the reaction of the opposite charges in the two plates prevents either being

entirely discharged by a single touch, unless both are touched at the same moment, when the two electricities will entirely neutralize each other.

If the plates are removed beyond the distance at which they can sensibly act upon each other, the electroscopes both of B and A will diverge, for the two charges are now free to act on bodies within their influence, and therefore repel their respective pith balls or gold leaves. Either plate can now be readily and perfectly discharged.

142. The inductive action of our two plates is not only affected by their distance one from the other, but also by the nature of the substances which may lie between them. Thus if, when the plates are very near one another, a piece of glass be placed between them, the inductive effect will be greater than when air alone intervenes. A plate of shellac will further increase it, and sulphur will have a still greater effect. Each insulating substance, or *dielectric*, as it is called, has a natural property appertaining to itself with respect to induction, which is called its *specific inductive capacity*, and is the converse of its *specific inductive resistance*; the former being its power of *effecting* induction, the latter its power of *resisting* induction.

The specific inductive capacities of the chief insulating substances employed in telegraphy are given by Jenkin.¹

Air being taken	= 100
Resin is approximately	= 177
Pitch	= 180
Bees'-wax	= 186
Grass	= 190
Sulphur	= 193
Shellac	= 195
Paraffin	= 198
India Rubber	= 280
Hooper's Vulcanized Rubber	= 310
Gutta Percha	= 420
Ditto Willoughby Smith's	= 359
Mica	= 500

¹ Text-books of Science. Electricity and Magnetism.

143. The two insulated plates, A and B, form a *condenser*; so called, because by such an arrangement we are enabled to *condense*, or accumulate upon a given surface, a greater quantity of electricity than it would contain were it not for induction.

When the plate A is submitted to the influence of the negative charge of B, the greater part of its positive electricity is attracted to the side nearest B. The tension of the opposite side of A is now, therefore, less than that of the source from which it was charged; so that, if it is placed in communication with that source, it is able to receive a second portion of electricity. This will decompose a second portion of the electricity of B, the positive part of which passes to the earth when the plate is touched, as in the former case; A can now receive a third portion, and so on, until its tension becomes equal to that of the source.

A pane of glass, coated on both sides with metal foil to within an inch of its edge, will represent the plates A and B separated by glass. This forms a convenient condenser. A still more convenient form is the *Leyden jar* (Fig. 42*), a wide-mouthed bottle, coated with foil inside and out, three-fourths of its height. The foil on the outside may be considered as taking the place of B; that on the inside, the place of A. They are called the *outside and inside coatings*.

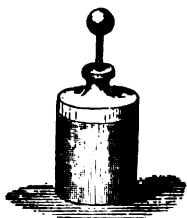


FIG. 42*.

Condensers may be made of plates of metal foil, divided one from the other by any good insulator. The thinner the dividing insulator, the greater the inductive effect of capacity.

144. The *capacity* of a condenser, or its power of storing up electricity, is proportional to the extent of the surfaces exposed to induction, to the distance between them, and to the specific inductive capacity of the insulating material used to separate them. As mica has a high specific capacity, and can be split very thin, it is a fit substance for the dielectric. Gutta-percha is unsuitable except for a temporary purpose, because in thin sheets it quickly becomes brittle.

When a condenser whose plates are separated by air only is

charged or discharged, it attains its full charge, or loses it completely in the first instant. But other dielectrics have the power of (as it were) absorbing electricity quickly at first, more slowly afterwards. The absorbed charge is also given out slowly, so that if a Leyden jar, or a condenser of paper, or mica, be discharged, and left insulated, several small discharges may afterwards be obtained from it. This phenomenon is more fully considered in treating of submarine cables.

A unit of capacity is as necessary as a unit of resistance. The same may be said with reference to a unit of electromotive force.

The unit of electromotive force is called a *Volt*, after Volta; the unit of capacity, a *Farad*, after Faraday—a microvolt is one-millionth of a volt, and a megavolt is one million volts. The megafarad and microfarad have corresponding values. The volt is as nearly as possible the electromotive force of a Daniell cell; it is exactly equal to 0.9268 of that force.

Clerk Maxwell defines a farad as the quantity of electricity which flows through one ohm resistance during one second from an electromotive force of one volt, and is equal to the charge produced in a condenser whose capacity is one farad.

The condensers used in telegraphy are made so as to expose a large surface to inductive action, and are constructed of alternate layers of tinfoil and thin plates of mica, or paper saturated with paraffin or ozokerit,¹ arranged like the leaves of an interleaved book—the metal plates being the printed leaves, the paraffin being the blank paper. Each *alternate* metal plate is connected so as to form two distinct series, insulated from each other; one of which may be connected with the object to be tested, the other with the earth.

A condenser of the capacity of one microfarad (about 3 knots of the Atlantic cable) may be made of 37 plates of stout tinfoil, each $7\frac{1}{4} \times 6$ inches, separated by two varnished sheets of thinnest bank post paper, hotpressed. The two series will consist of 18 and 19 sheets of foil respectively, there being one extra sheet

¹ Ozokerit is a substance lately introduced for making candles. The material used for condensers is in the crude or unbleached state.

in the series, which forms the *outside* of the condenser. This series is connected to earth, so as to cut off exterior induction.

The paper must be well dried, and may be dipped in or brushed over with hot melted paraffin.

Procure a cast-iron plate, somewhat larger than the sheets of paper, standing on four feet, so as to admit its being heated by a gas-burner under it; the surface must be flat and smooth, and should have a channel round its edge to collect any surplus paraffin.

Cut the paper into sheets large enough to leave about an inch margin when a metal plate is laid on them, and cut away *each* of the two top corners, as in the figure—cut away *one* of the two top corners of each metal plate, as in the figure.

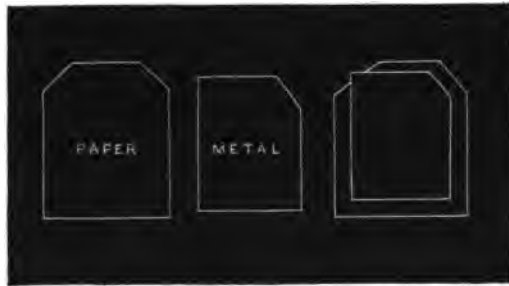


FIG. 43.

Smooth the plates carefully, and make them up into two books or sets, one of 18, the other of 19 plates, by soldering together the top corners which have not been cut off.

Lay a piece of paper on the hot plate, and varnish it over with the melted paraffin with a flat camel's-hair brush. Lay the outer plate of the set of 19 upon the paper, as shown by the figure; varnish it, and cover it with two sheets of paper, varnishing each as it is laid on. Next lay on the outer plate of the set 18, with the soldered corner at the cut corner of the paper opposite to the first set; varnish and cover with paper as before, and again lay a plate of the first set, and so on. By this method the two sets of metal plates will be interleaved one with the other, but will be insulated one from the other by the paper.

Each sheet must be carefully smoothed as it is laid, and when the set is complete it should be placed between two warm metal plates, and pressed with about 8 cwt., the object being to press out the surplus paraffin and consolidate the whole mass, so as to prevent the condenser altering in capacity from after alteration in the distance of the plates. Two thicknesses of paper are used to ensure the insulation, which would be destroyed by a small hole or spot in the sheet. A detector and 10 or 20 cells should be placed between the two sets of metal plates to show if the insulation remains good during the process.

After the condenser has cooled thoroughly, it may be compared with the standard by one of the methods for the comparison of condensers; if its capacity is found too low, it may again be pressed; and, if this fails, more tinfoil must be added; if too great, some foil can be removed.

When finished, it may be placed between two pieces of wood screwed together with wood screws, so as to maintain an uniform pressure, and enclosed in a box, with terminal screws.

When mica is used, the process is similar; but as mica is elastic, the capacity varies with the screw-pressure which has been applied. A mica condenser is much smaller in bulk than one made with paraffin and paper, because of the greater specific inductive capacity of the insulator.

The following method of comparing condensers will be found sufficiently accurate for ordinary purposes. The swing or deflection of a Thomson galvanometer through which a given condenser is discharged, will always be the same after charging with the same number of cells of a constant battery, whatever the potential of the battery may be, provided battery contact has been prolonged sufficiently to effect the charge, and that the discharge is taken immediately. And with equal potentials the swing varies almost exactly with the capacity of the condenser, so that if one produce a swing of 100 divisions on the scale, and another 200 divisions, the second has double the capacity of the first.

Provide a condenser of known capacity, adjust the potential of a Daniell battery so that a convenient deflection (the larger the better) is produced. Note this deflection, and adjust the

capacity of each of the condensers to be tested until the deflection due to the required capacity is obtained. The battery-contact must be prolonged—say 30 seconds—and the deflection must be taken immediately it is broken.

The swing varies almost exactly with the potential of the charging battery, but is, as has already been shown, constant with the same potential.

145. The *condensing electroscope* is useful for detecting electricity of very feeble tension, such as that of a small battery. It is an ordinary gold-leaf or Peltier electroscope, with two condensing plates attached, and may be roughly constructed in the following manner (Fig. 44):—

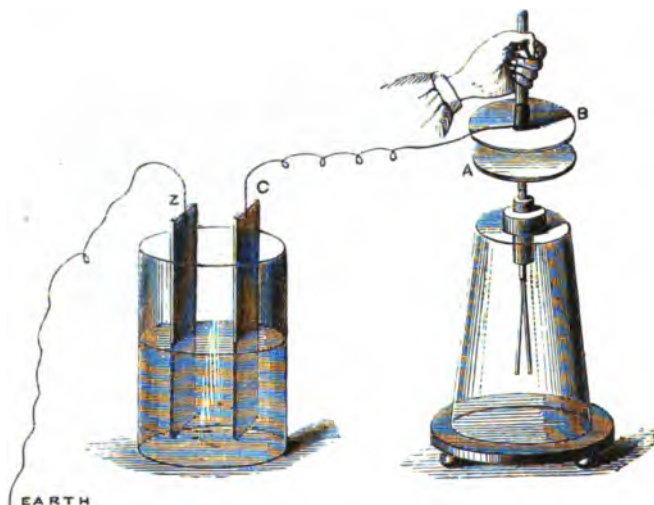


FIG. 44.

Cut out two discs of thick sheet zinc; flatten them; fix one (B) on an insulating handle; attach the other (A) to the wire of the electroscope. Drop three small pieces of hot sealing-wax on A, or varnish it, so that, if B be placed on it, the two shall lie as closely together as possible without touching. Wood discs, coated with tinfoil, will do.

Place B upon A; connect B with the positive pole of the battery; it will receive a very feeble positive charge. Touch A with the

finger; its positive electricity will pass to the earth,¹ and B will be enabled to take up an additional quantity of electricity from the battery. Remove the finger from A, and, *after having done so*, lift off B by its insulating handle, the leaves will diverge. With a carefully-constructed apparatus the phenomenon of repulsion can be exhibited with one or two cells of a battery (21). The plates should be of brass, 6 inches or more in diameter; ground one upon another with fine emery, so as to be accurately flat, and touch in every part (induction is greatest at the smallest distance); they are then carefully lacquered to insulate one from the other. Care should be taken to keep the faces parallel while separating the plates.

146. The *electrophorus*, a most convenient apparatus for obtaining electricity for experiments connected with telegraphy, owes its power to induction.

Procure a circular tin dish, similar to the lid of a canister, about 9 inches diameter and $\frac{1}{4}$ inch deep; fill it with melted sulphur; scrape or grind the surface perfectly flat, and paste a slip of tinfoil, 1 inch wide, over the edge of the tin and across the face of the sulphur. Make a wood disc, perfectly flat, of 7 inches diameter; cover one side smoothly with tinfoil, and fix upon the other side an insulating handle of varnished glass, or ebonite, by which the wood cover may be placed upon the sulphur cake with its tinfoil side downward.

If the sulphur and the wood cover be warm, the former well rubbed with dry silk, cloth, or flannel, and the cover placed upon the sulphur, when the cover is raised it will be found charged positively, and will give sparks each time it is replaced, touched and raised, for a considerable time. By the friction, the sulphur is excited negatively, its positive electricity passing to the earth. When the cover is placed upon it, the electricity of the cover is decomposed by the inductive effect of the charged sulphur; the — passing to the earth by the strip of foil, and the + remaining upon the cover, being held fast by the — of the sulphur. When the cover is raised, its charge is free to act again on surrounding

¹ The size of the earth being infinite, as compared with that of any electrical apparatus, its potential is unaffected by any quantity of electricity which can be taken from or added to it by artificial means.

conductors. The same effects recur as often as the cover is removed, until the excitation of the sulphur ceases.

A disc of ebonite is much more efficient and convenient than the sulphur cake. A brass pin is fixed through the ebonite which conveys the negative electricity from the covering movable plate to the earth, so that it is not necessary to touch the plate with the finger. This apparatus produces positive electricity.

If we make a machine which shall mechanically perform the operations just described, we shall be able to produce a large quantity of electricity from a very feeble original charge.

147. Faraday assumes that all bodies are more or less conductors, and that they are composed of small and distinct particles, which in the unelectrified state are quiescent, but in the electrified state are *polarized*; that is to say, arranged so that their positive and negative portions are turned towards each other, and that this state is one of constraint from which there is a tendency to escape. If the particles can maintain this state for a sensible time, then some degree of insulation ensues; but if they cannot do so, discharge arises. This action is not instantaneous, but progressive from particle to particle, each transmitting the force to the one next beyond it.

A current is therefore caused in a wire by each successive particle undergoing induction, and discharging itself to the next beyond it. The particles of a conductor offer very little obstacle to this induction and discharge, so that the current or transfer of force is carried on with extreme rapidity. In an insulator the progress is very slow, in some cases almost imperceptible.

148. When the wire is sufficiently near another conductor to be able to exercise an inductive influence upon it, this *exterior* induction must be completed by each portion of the wire before the current can pass on to the next.

When the wire is fully charged, it conducts precisely as if there was no induction, so long as the current is steady and regular. But if the current vary, its inductive effect varies also; and this change must be completed along the whole wire before the variation of the current can be transferred to the distant end.

When the battery-contact is broken, the induction must cease in each successive section of the wire before it is fully discharged.

As these changes occupy a sensible time, they retard the passage of the current.

149. A wire supported on poles, when conveying a current, influences by induction the wires near it, and also the surface of the earth. But the distance between them is so great that the effect is extremely small.

If one pole of a battery is connected to earth, and the other to a line-wire suspended on poles, well insulated and *disconnected* at the distant end, a current will pass into the wire till it is charged; that is, till it has attained throughout its length the same potential as the battery.

If the battery-contact be now broken, and the wire left disconnected, the charge will speedily be dissipated through the air and by leakage at the supports. But if the wire be put to earth at the sending end through an electro-magnet or galvanometer, immediately battery contact is broken a *discharge* will take place through the apparatus, as when the plates A and B are made to touch one another (141).

If the wire is short, the discharge will be completed before the apparatus has had *time* to move. The time occupied by the discharge increases with the length of the wire (other things being equal) until it attains sufficient duration to affect the apparatus. For the whole length of the wire must discharge itself at the one end.

150. For instance, if the key of a Morse instrument, con-

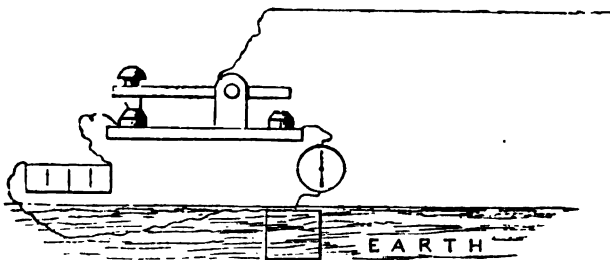


FIG. 45.

nected to a long, well-insulated wire, be pressed so as to charge the wire, and be then allowed to fall back very suddenly, the discharge or *return-current* will move the relay and produce a signal (Fig. 45). When the wire is very long, it is not necessary even that it be disconnected at the distant end, because its resistance is equivalent to partial insulation (12).

In England, the insulation is seldom perfect enough, on account of the dampness of the climate, to show marked results from induction; but in dry countries—such, for instance, as parts of Persia—the induction of one wire upon another is at times very marked.

151. If the line-wire is brought very near the ground, or if conductors in connection with earth, such as the metal caps of insulators, or the (so-called) *earth-wires*, are brought near the wires, the inductive action of the wire and earth will be increased, and the time of discharge increased also; and if it be covered with an insulator and buried, so that the wire is directly opposed on all sides to the earth, and the distance between them made exceedingly small, induction, prolongation of current, and retardation of signals will be enormously increased, and the discharge or *return-current* become very powerful. An immense Leyden jar, or condenser, has, in fact, been formed, having the wire for its inner, and the soil for its outer coating; this coating being in direct communication with the earth, like the plate B when touched with the finger, will part with the electricity set free by induction, enabling the wire to take up an additional charge from the battery. Each mile of coated copper wire 65 miles diameter (No. 16) has an inner surface of about 86 square feet, and an outer surface of 330 square feet. A hundred miles of such wire will therefore expose a very large surface.

152. Clark gives the following illustration in the "Submarine Report," p. 316, showing the similarity between a buried insulated wire and the Leyden jar.

Insulate a large tub filled with water, and place about half a mile of percha-covered wire in it.

Put one pole of a battery of 250 cells to earth, and connect the other pole through a key and galvanometer to one end of the wire, leaving the other end disconnected and well out of the water.

Place a copper plate in the tub, connect it by a wire to a second galvanometer, and put the other terminal of this galvanometer to earth. The water of the tub will thus be put to earth through the second galvanometer (Fig. 46). If a charge be sent into the half-mile of wire by moving the key, electricity of the same kind will leave the water for the earth. Both the galvanometers will move in the same direction, precisely as if they were both in circuit, whereas the circuit is not completed. There will be this difference: in the case before us, the needles will be

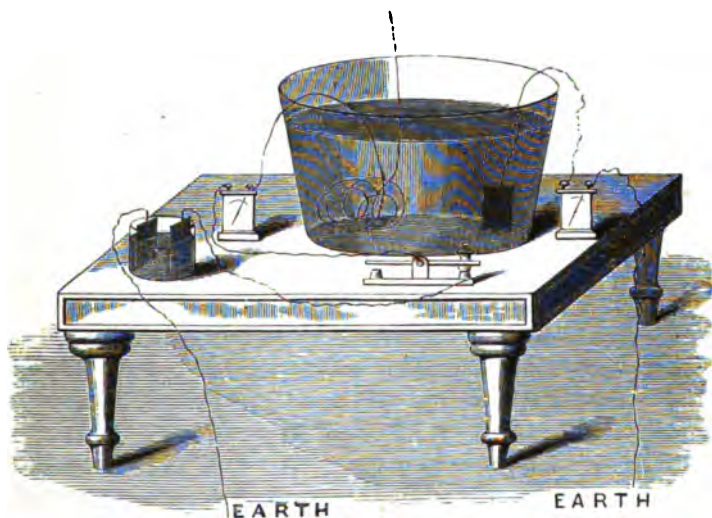


FIG. 46.

affected for an instant only, however long we may press the key; while if the circuit were complete, they would continue deflected until battery contact was broken.

The water, which is the outer coating of the wire, and which takes the place of the plate B, is put to earth. Hence the portion of its electricity repelled by the charge given to the wire (or plate A) passes to earth, and an additional quantity passes into the wire from the battery (141).

If the key is immediately pressed a second time, the same effect will not be produced, because the wire is fully charged.

If sufficient time is allowed to enable part of the charge to escape, the galvanometer will, upon pressing the key, be again deflected by a quantity passing into the wire, equal to that which had leaked from it; and the deflection will be a measure of the amount of leakage.

If the battery is disconnected from earth, and the wires marked *earth* in the drawing are connected to that pole of the battery which previously was to earth, exactly the same effect will be produced. A quantity of electricity will be transferred from one pole to the other. Two yards of covered wire, in a vessel filled with water, will show these effects well, if a reflecting galvanometer and 500 cells of a Daniell battery are used.

153. If 100 miles of covered wire be placed in water, one end insulated, the other end connected through an ordinary needle-instrument to earth, and a battery of 40 or 50 cells joined to the instrument; then if the key be moved as if to send a signal, the needle will be violently deflected for an instant by the current entering the wire to charge it. As soon as the wire is charged, the needle will regain the perpendicular, even if the key be still held in a position for sending a current.

If the handle be placed upright, so as to cut off the battery and put the wire to earth, the charge will rush from the wire, and the needle will again be violently deflected, but in the opposite direction.

Now, if the wire had been lying on a dry floor instead of in water, the needle would scarcely have moved, however powerful the battery; for though a current would enter into and charge the wire, the effect would last too short a time to do more than barely move the needle.

Similar effects will arise if the wire is connected to earth at the distant end, but they will be less marked.

154. If two lengths of 100 miles, or more, be placed on a dry floor, and if needle-instruments be inserted between each length, and at each end so as to form a circuit (Fig. 47), when signals are sent all the needles will move sensibly at the same time, sharply and distinctly.

But if the wire be put in water, or buried in the ground, and the circuit be completed through the earth in the usual

way, the needle at the battery end will move immediately the handle of the instrument is turned; the second needle will not move at the same instant, but a perceptible time afterwards; the third needle later still; and so on, showing that the current now travels more slowly than before.

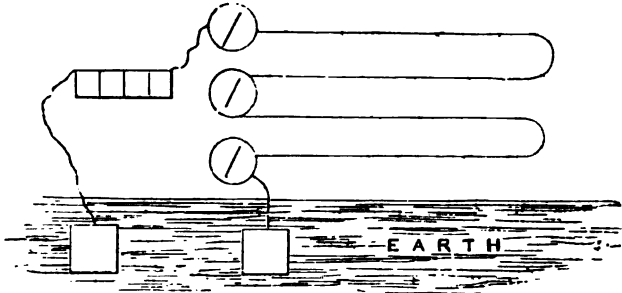


FIG. 47.

On a line of 1,500 miles the distant galvanometer was not affected till after *two seconds*.

When the handle is caused to break battery contact and put on the earth, a discharge will take place, and the needles will fall back one after the other, commencing with that at the battery end.

155. To use a homely illustration, it may be said that we must *fill* (charge) the wire with electricity before a signal can be sent, and to reverse a signal we must empty it, and refill it with the opposite electricity. A suspended wire soon empties itself, a portion of its charge escaping at each support; but a well-insulated buried wire cannot part with its charge anywhere except at the two ends. Hence, a slightly leaky buried wire can be worked faster than one which is perfect; and a long and very perfectly insulated suspended wire retards the extremely rapid signals of an *automatic* telegraph.

156. Induction is thus the cause of *prolongation of current* and *retardation of signals* in cables and underground wires. On a Morse printing circuit, the marks "run together" from the spaces between them being filled up by the current passing out from the cable after the battery-contact has been broken.

On a needle circuit the sending needle is jerked violently in the opposite direction after each signal, and frequently becomes demagnetized or reversed by the discharge or return-current. The receiving-needle moves sluggishly, and the signals run together, so that a letter of three movements appears like one of a single movement sent slowly.

157. Reversing the current after each signal facilitates the discharge at the sending end, by neutralizing the charge with electricity of the opposite sign, so that there is not so much to escape at the receiving end; thus rendering the received signals much more distinct.

158. In testing a buried wire, or even a well-insulated suspended wire, the distance of a disconnection may be estimated by the quantity of the return-current; for the longer the wire, the longer will be the time occupied in the discharge, the greater its quantity, and the larger the deflection of the galvanometer.

159. If two or three successive currents be sent into a long buried wire, they will travel on like waves, independently of each other. It is even possible to produce alternate waves of positive and negative electricity; that is, to charge the two ends of a wire oppositely.

160. As a wire, even when most free from inductive retardation, takes a certain time to charge, the current will not attain its maximum strength till battery-contact has lasted sufficiently long. The longer the circuit, the more firmly and slowly must the battery-contacts be made.

The phenomena of retardation and prolongation can be produced by combining condensers and resistance-coils, so as to produce an artificial line, equal in resistance and capacity to the line it is wished to imitate. The effect is best when a large number of small condensers connected by resistance-coils are used, so as to distribute the induction as equally as possible over the entire resistance in the same way that it is distributed upon the actual line.

DYNAMIC, OR MAGNETO-ELECTRIC INDUCTION.

161. A wire conveying a current has the power of inducing currents in neighbouring conductors.

If two wires are placed near each other, parallel but not touching one another, one connected with a battery by means of a key so that battery-contact may be made, broken, or reversed quickly, the other to a galvanometer of sufficient sensibility; it will be found that whenever a current is caused to pass through the former, the galvanometer attached to the latter is deflected by a current flowing in the *opposite* direction to the battery-current. The battery-current is called the *inducing* or *primary* current; the other, the *induced* or *secondary* current.

The *induced* current lasts but an instant; the needle falls back at once to zero, and continues unaffected so long as the *inducing* current continues to flow steadily. When battery-contact is broken, the needle is again moved; but now by an *induced* current flowing in the *same* direction as the battery-current, and, like the former induced current, instantaneous.

When the current is flowing, should it be *increased*, or should the two wires be brought nearer one another, the inductive effect is similar to that of *making* battery-contact: should the current be *decreased*, or the wires *removed further apart*, the effect is like that of *breaking* battery-contact. The action is greatest when the wires are parallel, and is null when they are placed at right angles. It is not confined to the extremities of the wires, but is equal throughout their entire length.

162. The effect in such a length of wire as can conveniently be arranged in a straight line is but feeble, but by coiling the wires into a spiral their length can be increased almost to any extent, and a very energetic action may be obtained. The wires must, of course, be covered with cotton or silk, to insulate the several turns from each other.

163. Construct two flat spirals of covered wire by coiling them in a similar manner to a roll of tape (Fig. 48); lay one flat on a table, and connect its ends to a galvanometer: call this the *secondary* or *induced* spiral.

Connect the other spiral to a battery through a key, and call it the *primary* or *inducing* spiral. After battery-contact has been made, lay the primary spiral upon the secondary quickly and smartly; the galvanometer needle will be deflected for an instant; if it be quickly removed, the needle will be instantaneously moved in the opposite direction; but in neither case will the deflection of the needle be lasting.



FIG. 48.

If battery-contact be broken sharply while the spirals are lying one on the other, the same effect will be produced as if they had been separated, and the restoration of battery-contact will produce the same effect as that of placing one upon the other.

If the spirals are suspended face to face, but not quite touching, they will attract one another so long as a current is flowing through both in the same direction, and will be mutually repelled when the current flows in opposite directions. This effect is produced during the whole period of the flow of current, not merely at making and breaking contact, and is not a phenomenon of induction, but is the same case as that of attraction of two parallel straight wires (113).

164. A still more powerful effect is produced by winding the wires upon bobbins made to fit one within the other (Fig. 49), and the effects of approach or removal, increase and diminution of current are the same as with flat spirals.

It is evident that if the wires are coiled side by side, or one over the other, on the same bobbin, one will influence the other when the current commences, ceases, or varies.

The pole of a magnet produces the same effect as the current of the inducing spiral or coil.

Connect the hollow bobbin of Fig. 49 to a galvanometer, and rapidly place the pole of a magnet just within the hollow: the

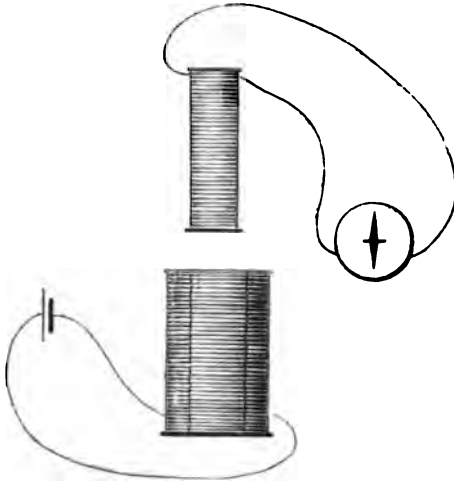


FIG. 49.

needle will move, and immediately fall back to zero. On removing the magnet, a similar movement will be produced, but in the opposite direction.

165. Place a bar of soft iron within the bobbin, and bring a pole of a bar-magnet near it (Fig. 50); the iron will be magnetized by induction, and the currents will be much more powerful than before; because in this case the effect of the increase and the diminution of magnetism in the iron will be superadded to that of the approach and withdrawal of the permanent magnet.

166. These currents are but momentary; they exist only

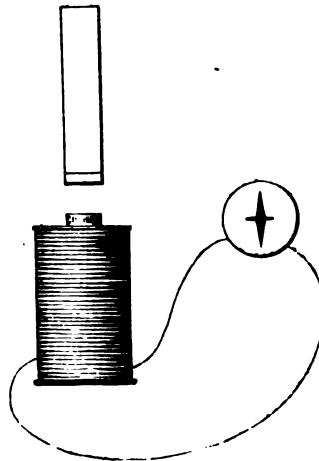


FIG. 50.

during the time the magnetic change is taking place; and the direction of the current produced by the *cessation* of magnetism when the permanent magnet is removed, will be the reverse of that set up by its *production* when the magnet is caused to approach. The more rapidly the magnetic change is brought about—that is, the more promptly the magnet is placed in contact with or detached from the soft iron—the more powerful is the induced current.

167. Currents may even be produced in coils of wire, without either the battery or the magnet, by moving or rotating them so as to be influenced by the earth's magnetism.

168. The greatest effect is produced when a bar electro-magnet, wound with thick wire, is covered with a considerable number of layers of fine wire. The thick wire forms the primary coil, the fine wire the secondary coil. The iron core can be more powerfully and quickly magnetized by a current than by a permanent magnet, consequently its inductive force is greater, when magnetized in that way, and that of the thick wire through which the battery current passes is superadded. To produce the greatest effect, the core must gain and lose its magnetism very rapidly; this result is best obtained when the circulation of induced currents in the core is prevented by composing it of a bundle of unpolished wires, partially insulated one from another by a thin coating of oxide.

The longer the fine wire, the greater the electromotive force of the coil. As much as fifty miles of wire have been used in the secondary coil.

Owing to the great force of the current developed, there is great danger of sparks passing between the several layers of wire so as to destroy the insulation. This is avoided by dividing the coil by one or more insulating partitions, and by winding it in such a way that the outermost layer of one portion is connected to the *outermost* layer of the next; the outside layers are by this means kept at not very widely differing potentials, and the passage of sparks over the outside is prevented. This apparatus is called the Ruhmkorff coil, or *inductorium*.

169. In all these experiments it is necessary to make and

break battery-contact very quickly. This is done by the self-acting make-and-break, or *Rheotom*.¹ In the Ruhmkorff coil the armature of the electro-magnet is hung upon a spring opposite one of the ends of the core, and when not attracted it rests upon a stop, against which it is pressed by the spring. The circuit of the battery and primary coil passes through this stop and the armature, thus: battery to stop, stop to armature and spring, spring to coil, coil to battery again; so that as soon as the battery is connected the circuit is broken by the armature leaving the stop; the attraction of the armature now ceases, and it is brought back to the stop by the spring, when it is again attracted. The rapidity of the vibrations of the armature are regulated by altering the tension of the spring by an adjusting screw pressing against its upper portion.

170. The induction currents set up in making and in breaking battery-contact are equal in quantity, although opposite in direction. This can be shown by placing a galvanometer in the secondary circuit; it will be deflected in one direction when battery-contact with the primary is *made*, and to an equal amount in the contrary direction when it is *broken*. If the make-and-break follow one another immediately, the needle has not time to move in the one direction before it is stopped and reversed by the contrary current. Hence it appears unaffected by either.

171. But the current produced in making contact has not the same electro-motive force as the current of breaking contact. The *extra* current of making contact, described in the next paragraph, retards the magnetization of the iron; hence the current induced in the secondary coil is weakened, because the force depends on the rapidity with which the magnetic change is brought about.

It follows from this, that if the galvanometer employed for the experiment have considerable resistance, the latter current alone will have power to pass, and if contact be made and broken rapidly, as by the self-acting make-and-break, the needle will be deflected steadily.

¹ A word formed from the Greek. It may be translated *current-cutter*.

172. If an electro-magnet is wound double, like a differential galvanometer, and the ends of the second wire connected so as to form a closed circuit, the current induced in this wire re-induces one in the first wire, and delays the demagnetization of the core; it acts as if it were a metal tube (131). We can now understand why it is necessary to cut a groove in a core and to slit the metal of a bobbin. The induced current is free to circulate over the surface of both core and bobbin, inasmuch as they are complete or *closed* circuits, the groove and slit break these circuits, and destroy the path in which they are able to circulate. The retardation of demagnetization is caused principally by the formation of extra currents, and therefore, when rapid action is needed, it is most important to prevent them.

173. In addition to setting currents in motion in neighbouring wires, the current in the primary wire acts as if it possessed inertia, inasmuch as the current is prolonged after battery-contact has been broken. In other words, a current exerts an inductive action upon the wire through which it flows, called the *induction of a current upon itself*. Connect one of the poles of a battery, not sufficiently powerful to give any spark by itself, to a mercury-cup, and close the circuit by dipping a wire connected to the other pole into the cup. If this wire is short, a feeble spark will be produced, but if it be lengthened the force of the spark will be *increased*, even though the extra resistance introduced by the lengthening of the wire will have enfeebled the current. If the wire is coiled on a bobbin, or in a spiral, the spark will be brighter still, even if its length be not increased, because each turn acts inductively upon those adjoining it. When a soft iron core is introduced the effect is again increased, because the iron which has been magnetized by the current will, in losing its magnetism, tend also itself to produce a current in the wire, and in the same direction.

Closing the battery circuit also induces a current in the conducting wire, but in a *contrary* direction to the battery current, so that the spark on making contact is the difference, while the spark of breaking is the sum of the ~~two currents~~.

It is not possible to produce a shock by the direct action of

a single cell. Yet if the current from one cell be made to pass through the coils of an electro-magnet, and the two ends of the coil are held in the hand, a shock is felt in *breaking*, but none in *making* battery-contact, an additional proof that the former current has the *higher potential*.

174. *To recapitulate*:—At the moment that a current commences to flow through the coils, it induces in the wire a current, lasting but an instant, flowing in an *inverse* direction to that of the battery, and opposing it so as to delay the magnetization of the core. Again, when contact is broken, the cessation of the battery current induces a second current, in this case flowing *direct*, or in the *same* direction as the battery current, and therefore prolonging its effect so as to delay the demagnetization of the core; by adding its force to that of the battery, it causes the spark which appears at the moment contact is broken to be much more powerful than that which is due to the battery alone. They are called *extra* currents; the direct is the more powerful, because its force is added to, while that of the inverse is subtracted from, the force of the battery current. The *inverse* current exists during the time the magnetism of the iron is *increasing*, the *direct* current while it is *decreasing*.

In an electro-magnet wound double, the battery current in one wire induces a current in the other, which is itself affected by the extra currents of the first wire.

175. The extra current direct can be well seen in the coils of gutta-percha-covered wire in a cable factory. They are generally a mile in length, and are coiled upon iron reels, so as really to form electro-magnets. If the reel is put into water, one end of the wire insulated, and the other first connected to a battery so as to charge it, and then quickly put to earth through a reflecting galvanometer, the needle is deflected by the usual static discharge (151).

But if the distant end of the wire is put to earth, and the coil then charged and quickly discharged as before through the galvanometer, the needle is deflected in the *opposite* direction, and to a far greater extent. The earth in this case connects the distant end of the coil with the galvanometer, forming a circuit for the extra current. The same occurs in an iron-sheathed

cable coiled in a tank. A similar effect is observed if the wire is not wound on an iron reel, but here the extra current is very feeble.

176. When the two extremities of an electro-magnet coil are connected by a wire, so as to afford a circuit for the extra current; the demagnetization of the core is so much impeded, that when battery-contact is made and broken rapidly the armature remains attracted. This principle has been employed in the construction of translators.

177. By connecting the ends of the coil to a condenser (143), the iron is demagnetized more rapidly, the spark is also considerably lessened.

The *extra* current of breaking contact enters the condenser instead of darting across from one extremity of the coil to the other, charging one plate + the other -, according to the direction of the current. For as the current sets from one extremity of the coil to the other, one end will abstract + electricity from, the other pour it into, the condenser plates. On again making contact these charges aid the battery current, because the direction of the condenser's discharge coincides with that of the battery current.

178. It has been shown that electricity and magnetism mutually reproduce one another. Not only can iron be magnetized by a current, but a current may be obtained by the action of a magnet upon a coil.

If, then, a pair of bobbins of insulated wire containing soft iron cores, connected as in an electro-magnet, is fixed upon a lever in such a manner that it can be forcibly detached from, or quickly placed upon, the poles of a permanent magnet, it may be employed in place of a battery for the production of transient currents in opposite directions.

Two or more such electro-magnetic armatures fixed on an axis so as to revolve in front of a series of permanent magnets, form a more powerful arrangement, and by a proper arrangement of switches or commutators, the two sets of currents may be made to flow in the same direction through a wire connected to the apparatus.

179. The *magneto-electric machine*, as this arrangement is

called, may therefore be employed in place of the battery for telegraphic purposes.

The lever arrangement is used for ringing bells, and was at one time employed for working a needle telegraph. The strength of the current will depend on the promptness with which the armature of soft iron wound with wire is detached from or placed upon the magnet, and therefore the current on removing the armature is the stronger, because it is generally removed with a jerk on account of the attraction of the magnet.

The revolving armatures with their coils are used for driving apparatus requiring a rapid succession of alternating (reversed) currents, or for supplying a constant stream of electricity in one direction by means of a commutator.

180. As the currents are produced only during the increase or decrease of the magnetism of the core, and as this effect is null when the core is at its greatest distance from the permanent magnet, the currents exist only during a small portion of the time occupied by the revolution of a single pair of coils. To approach a steady current such a machine must be driven with very great speed.

But by increasing the number of armatures and permanent magnets, arranging the commutator, and connecting the coils in a proper manner, the number of currents during a revolution may be considerably increased. A machine has been made with 88 coils and 66 magnets, to be driven at 110 revolutions a minute. There is a limit to the speed of revolution, because time must be allowed for the magnetization and demagnetization of the iron.

The action of such machines is this:—As each coil recedes from either pole of the magnet, the current in it is reversed; but the effect of *receding* from a N pole is the same as that of *approaching* a S pole, so that no further reversal will occur till the coil leaves the opposite pole. The current will cease as the coil reaches a position equidistant between the two poles.

181. M. Gramme has succeeded in producing currents sensibly constant. An iron ring, covered by wire, wound throughout in the same direction, is pivoted so as to revolve between the poles

of an U shaped horse-shoe magnet. The wire is brought out in loops at frequent and regular intervals, and the loops are connected to a series of insulated studs placed in a circle, two collecting springs being fixed to the frame at opposite ends of the diameter of the circle furthest from the poles of the magnet, where the inductive effect is null. These collectors are sufficiently wide to touch two studs at once, so that when the ring revolves contact is never broken. If the magnet be supposed to be laid flat on the table, and the ring placed flat also between its poles, the two poles and the two collectors will then each be at the extremities of diameters of the ring at right angles one with the other.

As the ring revolves, currents will be induced in each portion of the wire in succession, always flowing in the same direction, and will be collected by the springs.

182. As magneto-electric currents are produced by the *variation* in strength of the magnetism of the cores of the bobbins, the cores and coils may be attached to the poles of the permanent magnet so as to be magnetized by induction, and in this case a light soft iron armature revolving in front of them will, as it were, "short-circuit" their magnetism while passing each; so as to produce a sufficient change to cause a current, with a comparatively slight mechanical force.

PART V.

ATMOSPHERIC ELECTRICITY AND EARTH CURRENTS.

ATMOSPHERIC ELECTRICITY.

183. THERE is always free electricity in the air and in the clouds, acting by induction upon the earth and the wires. If the electrical condition of the atmosphere were constant, that of the wires would remain constant also, as far as regards their mutual influence. But it is not so.

When an electrified cloud approaches the wires, it charges them by induction; setting up a current which is generally in this country too feeble to affect the telegraph. In the Shetland Islands, however, during a snowstorm, the instruments have indicated the passage of electricity from the air to the earth, and in tropical countries a current sometimes flows through the wires for a considerable time.

But when thunder-clouds pass over them, the wires are affected strongly by induction, and are occasionally struck by lightning. The inductive charge is often so powerful that it escapes in sparks at the apparatus, demagnetizing or reversing the magnets, or fusing the coils, even although there may have been no actual lightning.

A very vivid flash of lightning occasionally fuses the line-wire, splits or grooves the poles, or destroys the coils of the instruments. No case has, however, occurred in which the person in charge of the apparatus has been injured; for the instruments afford the current a much more ready path than that given by the human body.

During a storm, the instruments should be placed on short circuit by connecting their line terminals across ; and if the lightning be very vivid, it may be best to disconnect them, putting the line direct to earth.

184. Wires buried in the ground and entirely disconnected from suspended wires are also affected by the inductive action of passing clouds, and vivid sparks have been observed passing between them and the earth.

Yet buried wires connected to open lines are very seldom damaged by lightning, occasionally, however, their coating has been found pierced with small holes. Insulated wires fitting tightly into lead pipes have frequently been injured, and cables lying in the sea are very liable to damage. In these cases the inner and outer coatings of the condenser are very near one another, much nearer than where percha wires are placed in the large pipes used for buried wires.

185. Cables must invariably be protected by a lightning arrester or *paratonnerre* ; important buried lines should also be protected when the apparatus can be placed within doors, for otherwise it will be very difficult to keep the apparatus dry, and the trouble from loss of insulation is greater than the risk of damage from lightning as regards buried wires ; but the danger is so great and so well understood with respect of cables, that it is always possible to secure careful attention to the apparatus needed for their protection ; so that when no suitable building is at hand, a vacuum tube protector, enclosed in a watertight box, may be used.

186. While telegraph circuits were comparatively long, as was the case here till recently, so little damage occurred from lightning that it was not thought necessary to use protectors, and, moreover, unless they are carefully made, there is danger of the communication being interrupted by their getting out of order accidentally. But since circuits but a few miles long, with frequent stations, have been erected, the percentage of accidents from lightning has increased.

The action on the suspended line-wire occurs within a limited space, and the charge escapes to the earth, expends itself upon the wire, or perhaps is limited by the resistance of the wire,

doing no harm if there be no station within several miles. Thus a long circuit of few instruments, and those distant from each other, is not greatly affected. But if the circuit be short, and a station near the place of the storm, as it must be if a storm occur on the line of such a circuit, the coils are damaged because they are in the path of the discharge. Apparatus on a short line is more frequently destroyed than on a longer line.

187. Tying a knot in the fine wire of a coil will often cause the spark to jump to the metal frame, and thus preserve the coil from destruction.

A very simple and efficient protector for *moderate* discharges may be made by twisting together two pieces of wire well covered with silk, enclosing the twisted portion in a little tube for protection. The two wires should differ in colour to show which is which. It should be placed between the line and earth, or if there is no earth-wire, and it is not thought desirable (for other distinct reasons) to fix one, it may be placed between the two coil-wires, although in this position it will not be so efficient.

A more efficient protector is made by winding the two wires side by side, on a brass tube six inches long, the tube being connected to earth. But one of the best protectors consists of two flat brass plates, each having a surface of about ten square inches, placed one upon the other, separated only by a piece of paper soaked in paraffin, or by a thin strip of ebonite placed at each side, leaving an air space between the plates. Guillemin proposes mica, which, he says, is better than paper, because it is not carbonized by the spark, so as to make earth, as paper will sometimes do. The plates must be very well made, and free from roughness, or points that would pierce the paper.

The *vacuum* protector, consisting of platinum wires connected one to each of the line-wires and one to the earth, sealed in an exhausted glass bulb, answers perfectly. The lightning generally destroys the bulb, but does not reach the cable.

188. The wires leading into a station from the line must not be allowed to pass too near lead gas-pipes, lest a spark should dart from one to the other, fuse the pipes, and set fire to the gas, as has occurred in one or two instances. For a similar reason

an *earth* should never be obtained from a lead gas-pipe. (See page 44.)

189. As long magnets retain their power much better than short ones, it is desirable not to use very short needles in signal instruments, where reversal might be dangerous.

It is better still to use soft iron needles, *induced* by a large magnet. These are very trustworthy, but the large magnets are sometimes *weakened* by the discharge.

EARTH CURRENTS.

190. Occasionally strong currents, sometimes steady, at other times changing from positive to negative very rapidly, appear in the wires. These currents are sometimes as powerful as that from eighty cells of a Daniell battery *on short circuit*, and will give sparks. The longer the line the stronger the currents, other things being equal. They have a *direct* effect upon the magnet without the aid of a conducting wire, so that the delicately suspended magnets of a magnetic observatory, and even the magnet of a Thomson galvanometer, are moved by them; and when the movements of the suspended horizontal magnet have been compared with those of a galvanometer, connected to a telegraph wire, the two have sensibly coincided, showing that both are due to the same cause. They are not caused by atmospheric electricity, for they cease if a wire be disconnected at one of its ends, and they appear equally in buried and in suspended wires. They seem rather to be caused by currents flowing from one part of the earth to another, which enter the wires by one of their earth connections and leave them by the other.

191. Lines running N.E. and S.W. are most frequently affected; lines lying N.W. and S.E. are not often disturbed, and if affected, the currents are weak. It seems, also, that the direction in which the current flows changes with the hour of the day, so

that one line may be more strongly affected in the morning, another in the afternoon. The current has frequently been seen to leave one circuit and to appear upon another previously free.

Their direction and strength are not determined by the actual course of the wires, but by that of a straight line drawn from one extremity, or earth-plate, to the other, modified by leakage to earth from bad insulation or *faults*, and sometimes also by the character of the soil, as affecting its conducting power.

192. Currents are always passing; but it is only occasionally, during what are called *magnetic storms* or auroras, they are sufficiently powerful to affect the ordinary forms of telegraph. They, however, frequently interfere with the more sensitive instruments, and with tests for the resistance of the wires. They are always present during an aurora, and have been observed to be steady when the sky presents a steady glow, but to vary rapidly in direction when streamers appear.

In the United States, where the "closed circuit" principle is extensively used, it has sometimes been found possible to detach the batteries, and to work with the earth currents so long as their force remains uniform.

There have been occasions on which all the telegraphs in America, Europe, and Asia, have been affected, or at least all those lines lying in or near the direction N.E. and S.W.

193. Currents are then constantly passing from one part of the earth to another, these may be called the diurnal or daily currents, and affect only the very sensitive telegraphs. It is thought by some that these currents produce the diurnal variation of the compass-needle, for the direction of the compass is known to change, very slightly, throughout the day. The most careful observations, however, which have yet been made, fail to confirm this view.

194. But in magnetic storms, when the earth currents are powerful enough to affect the ordinary telegraphs, the compass-needle, if sufficiently sensitive, is affected as if a straight wire conveying similar currents were placed near it.

These storm currents are irregular, their immediate cause is not known, but is supposed to be the same as that which pro-

duces an aurora. The telegraph always foretells an aurora, but it is often affected when no aurora is visible.

195. The diurnal currents, on the other hand, are regular, but their direction and time of greatest and least strength, differ according to locality.

In Dublin, the direction is easterly, from 9 P.M. to 9 A.M., south about noon, and westerly during the remainder of the twenty-four hours.

At Toronto, the current is wholly easterly; and easterly also at Munich, St. Helena, and the Cape. The easterly maximum in Great Britain occurs between 2 and 4 A.M., the westerly maximum between 3 and 5 P.M.¹

At Arconum, near Madras, the easterly maximum occurs at 5 P.M. The westerly at 9 A.M.,—Madras time.²

At Valentia, Ireland, the currents from the Atlantic cables are westerly between 6.30 and 9.30 A.M., and between 2.30 and 10.30 P.M.; easterly during the remainder of the twenty-four hours, reaching a — or westerly maximum at 4.30 P.M., and a + or easterly maximum at noon.³

196. When communication is stopped, it is possible, when the currents do not vary rapidly in sign, to restore it by the use of a magnet, so placed as to counteract their effect on the needle or armature: but this method is seldom satisfactory. The only efficient method is to abandon the use of the earth-plates at terminal stations, and to form metallic circuits. This can always be done when there are two wires which can be connected in loop. It is not absolutely necessary to loop the wires at more than one of the two terminal stations.

Where there are not two wires, the circuit may be extended by connecting another to it, which is so situated that a line connecting the termini of the connected lines lies out of the direction of the current at the time. If there are two circuits on which the earth currents are generally opposite in direction, but equal in force, these, when connected so as to form one, will be free from disturbance.

¹ Transactions of Royal Irish Academy, April 28, 1862.

² G. K. Winter.

³ James Graves.

These methods succeed best when the wires are well insulated, because any cause which brings them into connection with the earth permits the earth current to flow through them.

Where the apparatus admits of it, condensers may be placed in the line-wire, between the line and apparatus, so that the wire is completely insulated; this method is adopted in the Atlantic cables, which from their direction are peculiarly affected by the currents. This is the most effective method which can be adopted.

197. These *earth currents*, or as they are sometimes called, *deflections*, must not be confounded with the *earth battery* current set up between two dissimilar earth-plates (p. 45), or with the current which sometimes is set up when the conductor of a cable or buried wire is in contact with earth at a fault.

PART VI.

INSULATION.

198. WHEN a wire is suspended on poles it is fixed to *insulators*, to prevent the escape of the current at the points of support. When it is carried through wet tunnels, underground, or through water, the insulation must be *continuous*, and the wire is covered with gutta-percha or india-rubber.

199. The insulation of an overground line is never perfect, even in dry weather. There is a loss at every point of support even when the insulators are clean, and this is considerably increased when their surfaces are damp, more especially so when dusty, dirty with smoke, or covered with salt from being near the sea. When the wires are not galvanized, a slight coating of rust is formed upon the insulators by the rain dropping from the wires, which is injurious. The wires are often hung with spiders' webs, which, when covered with dirt and moisture, conduct; and on a long line the leakage from wire to wire, from this cause alone, cannot be altogether without effect. A very rough test will show how much insulation is affected by dirt or smoke, and too much care cannot be taken to keep the insulators clean.

200. As damp affects insulation so seriously, great care was taken in the earlier telegraphs to protect insulators from the rain by wooden roofs; but it has been found that such coverings are not only useless, but injurious. They do not themselves insulate, they afford no protection in fogs or continued rain, for then every part becomes equally damp. They harbour

spiders, which spin their webs over and among the wires. They hinder the drying of the supports, and prevent the rain washing off the dust which covers the insulators. The inside of a hollow insulator, or that part which is protected by a wooden arm, is always dirtier than those parts which are fully exposed, and damp dirt conducts far better than a film of dew or clean rain-water. Insulation is frequently improved by a heavy summer shower. There is therefore a great disadvantage in placing insulators under bridges, where they are quickly covered with smoke, and are hidden from the cleansing effect of rain. The umbrella-shaped insulator secures all the advantages of the roof in keeping an insulating surface dry in moderately wet weather, while it adds to its insulating power by increasing its length.

201. Complete exposure is most of all desirable on the sea-coast. It is true that a cover may protect an insulator from the effects of spray, but during storms the air is impregnated with water holding salt in solution, and this, when evaporated, lines the insulator inside and out with a thin layer of salt. If all the surface of the insulator were exposed, the next shower of rain would wash away this coating; but if covered the salt would be left, and the insulator would gain considerable conducting power with the slightest damp. Iron hoods are, therefore, undesirable, and should never be used except where they are absolutely necessary. They may be made with slits, so as to admit the rain and wind, and prevent the accumulation of dust. It is, however, so difficult to secure the insulation of a coast line, that the sea should be avoided as much as possible.

202. In order to form a correct conception of the relative merits of various kinds of insulators, it is best to consider them not as *insulators*, but as *conductors*, whose value depends on their resistance to conduction.

The conduction of currents through wires and metals occur through the mass or thickness of the materials, and is therefore a question of bulk or weight; but the resistance of insulators is almost purely a question of surface, and in insulators similar in other respects, the largest in diameter and shortest in length will conduct best, following the ordinary laws of resistance.

The best insulator is that which has the smallest possible diameter consonant with strength, with the greatest distance between the wire and the bolt or support; and which can be maintained in the driest condition in wet weather, while exposed freely, as regards its outer surface, to the cleansing action of rain.

Length is most easily given by a form like that of two cup-shaped insulators, placed one inside the other. A tube or double cone surrounding the wire and supported at its centre, and a *shackle*, must be *double* the length of an insulator fixed at its ends (such as an invert) to be equally effective; because the current escapes from the wire at each end of the insulator in the former, and at one end only in the latter case.

203. The affinity of a material for moisture, or its power to attract damp, is an important point. Glass, though a better insulator than porcelain, becomes damp much sooner. If a glass tumbler and a tea-cup, each filled with cold water, be brought into a damp warm room, the glass will be covered with dew long before the porcelain shows any signs of moisture. The glass supports of apparatus used for experiments on frictional electricity must be varnished with shellac, to lessen this affinity for moisture.

Cast glass has been very extensively used; but out of the hundreds of thousands of insulators put up fifteen years since, very few remain. It is probable that want of care in annealing may have been a principal cause of this failure; but even if due attention in this respect would render it more to be depended on, it is next to impossible practically to find out if the annealing be perfect or not, and glass at its best is but fragile and treacherous. It is, however, largely used in Switzerland. Glass insulators break very rapidly in those deep railway cuttings into which the sun does not shine till late in the morning, so that, instead of being warmed gradually, they are heated suddenly at a time when the sun has attained great power.

It has often been observed of electrical machines, that a cylinder has more power, and works better in a room, than a plate. Snow Harris considered that this arose from the nature of the surface of the glass, and found that a plate machine

constructed of several layers or thicknesses of window-glass cemented together was as efficient as a cylinder, because window-glass, like the cylinder, is blown, while plate-glass is cast. Reasoning from this, Mr. Brooks, an American, lately introduced a blown-glass insulator in the form of a narrow-necked bottle. It certainly gives very good results as regards insulation—indeed, as far as trial-tests go it is superior to all materials, except newly polished ebonite. He considers it owes its effect to what he calls an “air surface ;” that is, to a surface which has not come into contact with anything but air, while hot. This insulator has, however, many disadvantages.

204. Ebonite insulates much better than glass, and is far less apt to become damp than even porcelain. It is the best material yet known for the insulation of electrical apparatus. Compared with porcelain or earthenware, it less easily becomes wet in mist, but more easily in rain. Rain forms detached drops upon a surface of earthenware, but covers ebonite with a continuous film. Thus the latter acts with most advantage when it forms the inner cup of a compound insulator, and is protected by earthenware from the direct action of rain.

The surface of ebonite becomes rough and spongy, so as to retain dirt, and it matters not how perfect the *substance* of the insulator may be if its *surface* is defective.

The change extends only to a very thin film, so that when repolished, it behaves as well as at first. This shows conclusively the effect of surface.

For many purposes it is most excellent. An insulator may be made small and light, and will yet be sufficiently strong not to be broken accidentally or by the strain of the wire. For this reason it will afford a uniform, although perhaps not a very high insulation. This is an advantage which cannot be overlooked.

Moreover, its very colour, and the unpretending appearance of a small insulator, protects it greatly from wilful damage, and would be an advantage in wild countries. It is found that where the telegraph is exposed to mischief, a large white porcelain insulator is quickly broken ; earthenware is less attacked, and a small ebonite insulator not at all. Mischievous boys

cannot hit the small mark with stones, nor does it tempt them by its inviting appearance. Many who would not take the trouble to break an unpretending black cup, cannot resist the temptation of throwing at a large white one.

205. The best material for an insulator is a really good porcelain, thoroughly vitrified, so as to insulate perfectly even when unglazed. Its value arises principally from its polished smooth surface, which resists the formation of a continuous film of moisture, does not retain dust, and is washed clean by rain.

The objection to porcelain is, that considerable skill is required to select it, and to distinguish between a good and an inferior sample. As it is a compound of several substances, it is difficult to secure uniformity of composition, and much is left to the care and honour of the manufacturer.

Though a *good* glaze does not deteriorate by age or exposure to the weather, it is difficult to distinguish between a good and a bad glaze by inspection or electrical test, and it is quite possible that a glaze which *appears* good and insulates well may crack by age.

206. Brown stoneware is both excellent in quality, cheap, and durable. Its surface is not equal to that of porcelain, so that it never insulates so well as the best specimens of the latter, but the glaze never cracks. Again, it is not a compound; so that when a manufacturer possesses a suitable clay, and takes care in its preparation, the uniformity of his ware may be depended on. It is also comparatively easy to distinguish its quality, and to detect faults in its manufacture.

207. Small pieces of ware are more easily burned, and therefore more likely to be perfect, than large ones. There is therefore a great advantage in forming an insulator of separate hollow pieces or cups, placed one inside the other, and fastened with cement: if one is defective, there is a probability the others will be sound; and if the pin or bolt be covered with an insulator (such as ebonite), insulation will not be destroyed if the earthenware be entirely useless.

208. New insulators may be dipped while dry and hot in melted paraffin with excellent immediate results, but the surface retains dirt more easily.

209. Insulators should be tested before they are sent out from store. It is best to test the separate pieces before they are put together. A trough lined with lead is fitted with a rack to fit the porcelain cups; the cups are arranged mouth upwards, and the troughs filled with acidulated water to within half an inch of their edges. The edges are slightly smeared with grease, paraffin, or turpentine, to prevent the water spreading over them, and the cups are nearly filled with water; and if the ware is glazed, a small portion of glaze is ground off at the top of the insulator to test the body.

One pole of a battery of 250 Daniell cells is connected to the lead of the trough, the other pole to an insulated handle, a very delicate galvanometer being placed in circuit. The conducting wire is dipped into the water contained in each insulator in rapid succession, and if any one is faulty the needle moves. The acid must be very carefully washed off after the tests. If a delicate reflecting galvanometer is used, the acid is unnecessary. From its power of repelling water, grease greatly aids insulation; paraffin, again, enormously improves it; so that in testing samples it is necessary to ascertain carefully that they have not been coated with these substances.

210. In order to learn the comparative value of different kinds of insulators, they should be fixed upon standards exposed to the rain equally on all sides, and tested when the weather is uniformly wet. Almost any insulator will suffice in fine weather, while that which tests best in slight rain may not give the same result in extreme wet, when the insulation is most tried.

The best method of testing is to fix as large a number as convenient, certainly not less than ten of each kind, upon a pole, connecting them by a wire to represent the line-wire, and fixing a second independent wire to their bolts, to represent the earth, and to determine the leakage from one wire to the other.

To obtain good results the following precautions are necessary. Fix a pole not less than 20 feet high in an open place not sheltered in any way or on any side, place the arms on which the insulators are to be fixed at least two feet apart, the insulators themselves a foot apart. Do not place all of the same

kind together, but rather alternate or mix them as much as possible, so as to obtain an average of exposure for all.

Take special care that the wire representing the line touches each one closely all round and uniformly as to the number of turns: let it be all the same gauge. The object is to ensure equal surfaces of metal in contact with the porcelain, because the leakage takes place from each point of the wire over the *surface* of the insulator, and consequently if the wire does not touch uniformly, the leakage will vary with the variation of the surfaces in contact. If possible, divide each set of ten in half, making duplicate sets of five each. If these do not test alike there is probably a defective insulator among them, which will vitiate the test and must be removed. Never use separate gutta-percha or other insulated leads from each set to the testing room, for these will become more or less damp on their surface and will vary in insulation, one from the other, more perhaps than the insulators themselves. Use only one wire, employing an assistant to shift it from one set to the other.

It is seldom that rain falls steadily and uniformly, so that if the testing lasts even five minutes there will often be considerable difference in the amount of moisture during the interval. After testing all the sets, commence again in the reverse order; if the two series agree, the observation is a good one. As the object of such tests is not so much to find the *absolute* resistance of the several specimens as to ascertain their *relative* value, it is better not to occupy time in testing in units, but rather to read a simple deflection, so that the tests may be made as rapidly as possible, ensuring the greatest possible uniformity of circumstances; but with the greatest precaution, the tests will frequently be extremely anomalous. The approximate resistance may be calculated afterwards.

211. Speaking generally, the best insulator is not that which tests best when quite new, but that which bears exposure the best, and therefore no tests are of any value which have not extended over several months. However carefully this experimental testing may be conducted, it is not altogether satisfactory; the only true method is to insulate two wires on the same poles for a distance of ten miles or more, and to test them every

damp day for six months. It is obviously useless in any case to test in dry weather.

212. The following is the result of tests made in a situation quite free from insects, but somewhat smoky—Gloucester Road, Regent's Park, London—during 12 months, 1868-9:—

Mean Comparative Loss.

Brooks' double cup (<i>American glass</i>) . . .	5	parts leakage.
Varley's brown ware	20	" "
Porcelain	26	" "
Double cones, porcelain	51	" "
Shackles, ditto	82	" "

The porcelain insulators were made very much wider than the Varley's to render them less liable to be blocked up by insects. The test, therefore, does not show the difference between stone-ware and porcelain so much as that between a wide and a narrow opening.

213. Two wires on a railway were insulated, one with Brooks', the other with Varley's—there were 44 of each. On a very foggy night the insulation of the former was 290,000, of the latter 150,000 ohms; but the following morning, just after the sun broke out, Brooks' tested 390,000, Varley's two millions. The narrow opening of Brooks' prevented the evaporation of the moisture.

The effect of iron caps may be judged from the following:—

Porcelain, without caps	38	parts leakage.
„ with open caps (or cages) . . .	44	" "
„ with closed caps	55	" "
Small earthenware insulator, without caps	50	" "
„ „ „ with open caps	50	" "

The tests also show that, with a wide cup, a bracket gives a better result than an arm, probably because splashing is avoided; the leakage being 26 and 38 respectively.

214. Periodical cleansing is very necessary. The interior of the umbrella or cup is a favourite resort of spiders, which spin

their cocoons and deposit their eggs within them. Straw and dirt adhere to the web, so as, in some places, especially under trees, completely to fill the hollow and destroy the insulation. It is, therefore, well to choose the late autumn for cleaning, because of the spiders, as well as on account of the coming winter.

In practice a long and narrow single cell gives a better insulation than a double cell of half the depth; but, as is shown above, it dries more slowly, and is liable to be quickly filled by insects.

If a line pass through an open country free from trees, the openings may be narrow; but if it pass near or under trees, they must be wide, less liable to be bridged across, and more easily cleaned. In the high roads of Ireland insects are very numerous and troublesome. In India, it is said that, however large an insulator may be, an insect of the proper size is always ready to inhabit it.

Spiders will not build in insulators fixed on creosoted poles, nor in those ebonite insulators which have been varnished with a solution of ebonite in naphtha to improve their surface after it has become rough. But the repelling effect ceases as the smell passes off.

215. After a long succession of dry weather, inland lines become so much coated with dust, that on the first damp day of autumn, before actual rain has fallen, the insulation is lowered and communication becomes very difficult, as much so, perhaps, as at any time, except during an exceptionally violent storm of wind and rain. When rain falls, the difficulty at once vanishes.

216. For a short line a small, single shed, cheap insulator will be amply sufficient, and its maintenance need not be very carefully looked after.

For a long line the best double shed insulators must be used; they must be kept clean, and carefully renewed when broken.

Washing or smearing with paraffin oil is an excellent method of improving insulation for a time; the effect lasts about six months.

In very smoky places it is perhaps better to change the insulators occasionally, for the dirt adheres too firmly to be removed by ordinary washing.

217. When insulation is imperfect, when the wires touch the ground, a wet wall, the boughs of trees, grass, or the like, part of the current escapes to the earth. This *fault* is technically called "*earth*."

218. Imperfect insulation also allows the current to divide itself between all the wires on the pole in proportion to their respective resistances; and as the shorter the wire the less the resistance, the tendency is to escape from a long circuit into a short one. The current divides in like manner when the wires touch one another, or are connected by wet cotton waste (which is often thrown on them by engine-drivers), by kite-strings, or other conductors. This *fault* is called "*contact*;" and when it arises from the effect of bad weather on defective insulation, "*weather contact*."

219. When the current escapes to the *earth*, the signals are simply weakened, and the loss can be made up by increased battery-power; but when it leaks into *another wire*, it confuses the signals passing upon that wire; and when signals are sent on the second wire the current interferes with that passing on the first wire. If the battery-power is increased to make up for the loss of current, the interference is increased also. Thus "*weather contact*" is a far more serious evil than leakage to the earth.

It is an advantage, therefore, if the leakages can be intercepted and conveyed to earth by placing an earth-circuit between wire and wire. The signals will, it is true, be weakened; but the loss of current may now be compensated by increasing the battery without affecting the other circuits on the poles. To obtain the best result, these earth-wires should be soldered to the insulator-bolts or to the iron bracket holding the insulator, which is provided with a tinned iron pin for this purpose; the earth-wire must be attached to the bracket after the latter has been fixed to the pole, and it is very much easier to solder to the small pin than to the mass of the bracket. If the wires are not soldered to the insulator-bolts, they should

at all events be tightly screwed between the nut and the washer. The branches of binding wire from the several insulators are connected to the main thick wire which is fixed to the side of the pole.

When wood arms are used, and it is considered desirable not to lose the insulation afforded by the wood, the earth-wires may be wrapped closely round the arm, or sunk in a saw groove; but they must be placed as close to the pole as possible, so that if a wire fall on the arm it may not touch them. They are screwed tightly between the head of the bolt by which the arm is fixed and its washer, so that the leakage through the wood, as well as that over its surface, may be conveyed to earth. The wire obviously must not be covered with paint or tar. This method is not so effectual as the first, nor is the insulation of the wood of much service in wet weather.

When a single line-wire is carried on the pole-top, it is not necessary, indeed not desirable, to fix an earth-wire to it; because its leakage cannot pass into the other wires, being intercepted before it reaches them; while its own support, being fixed on the end grain of the wood, makes good earth through the pole.

220. These earth-wires, however, do much more harm than good when they do not make "good earth;" that is, when there is any resistance between them and the earth. To form a good earth-connection, it is well to attach a thick wire to the pole, and to coil it in a spiral under the pole-foot, taking care, of course, that it does not become tarry. When poles are set in rock or on viaducts these wires must not be used. If, however, there be special reasons for protecting such places, let an uninsulated wire be run from pole to pole, connected to the earth-wires, and put to earth at the nearest and most convenient place.

When rain occurs after a long drought, it sometimes happens that there is more weather-contact on the first wet day than afterwards. The soil is dry, and the earth-wires are partially insulated. They do not make good earth until the soil has become damp. The insulators are also covered with dust, which forms a conductor until it is itself washed away by the rain.

221. If these wires are carried to the top of the pole, and made to project above it, they form useful lightning-conductors.

222. If a wire lies on the metals of a railway, or other perfect conductor in communication with the earth, the resistance of the fault being nothing compared with that of the wire beyond it, all the current will pass to the earth, and none to the receiving station. This fault is called "*dead earth*."

If the wire lies on the ground, touches rusty metal, or any other *imperfect* conductor in communication with the earth, the fault will offer more or less resistance, and is technically called "*partial earth*." The greater the resistance of the fault the stronger will be the current which passes on to the receiving station, and *vice versa*. The same occurs when two wires touch, or are in contact; thus a *contact always gives earth*.

223. The effect of a fault, whether earth or contact, is to decrease the resistance of the circuit, to work the batteries harder by augmenting the current passing out to the line, and to decrease the current received at the distant station.

But its effect on the signals will depend on its position on the line, and this position will determine also which of the two terminal stations shall be most inconvenienced by it, for a fault which prevents B reading A, may not prevent A reading B.

Let A B be a wire on which A is the sending and B the

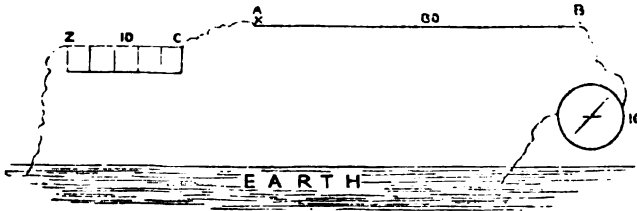


FIG. 51.

receiving station. Let it have a resistance of 80 ohms, and be perfectly insulated.

Place a battery at A, having an electromotive force, E , of 1,000, and a resistance R of 10 ohms; connect one pole to the

line, the other to earth. Place a galvanometer having a resistance of 10 ohms at B.

When perfect, the total resistance of the circuit will be—

$$\begin{array}{r}
 80 \text{ ohms, line.} \\
 10 \text{ „ instrument.} \\
 10 \text{ „ battery.} \\
 \hline
 100 \text{ ohms} = R. \\
 \hline
 \hline
 \end{array}$$

In this case, in which the line is perfectly insulated, the entire current passing from the battery will act on the receiving instrument.

The force of the current C is, by Ohm's law, equal to $\frac{E}{R}$.

It will be $\frac{1,000}{100} = 10$. The strength of the signals, when the line is perfect, will therefore be 10.

Suppose, now, a fault to occur connecting the wire to the earth, and offering a resistance of 20 ohms. This will lessen the total resistance of the circuit in the same degree as if a wire of 20 ohms' resistance were fixed to the line at the fault, and connected to the earth; affording a second path for the current, which would split or divide at the fault into two parts, according to the resistance of the two routes open to it—the greater part following the shorter route. Thus, although the current passing out from battery to line will be increased, the strength of the signal will be decreased.

First Case.—Let the fault be in the centre of the

line of 80 ohms.

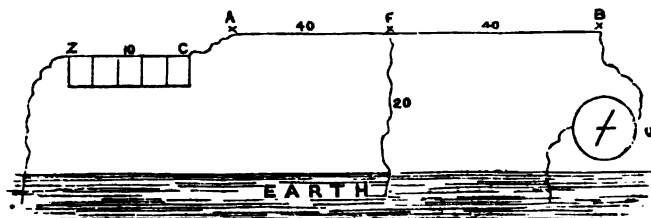


FIG. 52.

The two circuits beyond the fault will then be:—

1. That by the line and instrument, $40 + 10 = 50$ ohms.
2. That by the fault itself 20 „

Their joint resistance¹ will be $\frac{50 \times 20}{50 + 20} = 14.3$

Adding the resistance of the battery, 10 ohms,
and the wire between the battery and the fault,

40 ohms 50.0

The total resistance will be 64.3

and the current passing out to line $\frac{1,000}{64.3} = 15.5$ parts instead of 10.

The two circuits between which the current will divide at the fault having, respectively, resistances of 20 and 50 ohms, are in the proportion of 2 to 5. If, therefore, the current of 15.5 be supposed to be divided into 7 parts, 5 parts will pass to earth by the fault, and 2 parts by the line and instrument.

Thus $\frac{15.5 \times 2}{7} = 4.4$, which will be the strength of the signal, instead of 10.0

Second Case.—The fault at the receiving station B.

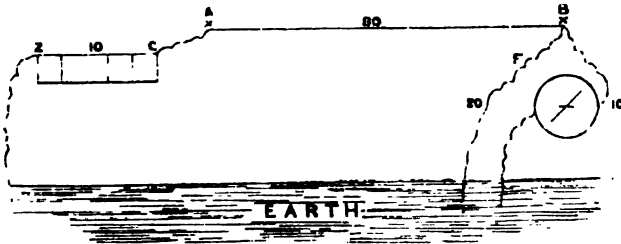


FIG. 53.

The two circuits beyond the fault will be :

1. That by the instrument . . . = 10 ohms.
2. That by the fault = 20 „

Their joint resistance $\frac{20 \times 10}{20 + 10} . . . = 6.6$ ohms, nearly.

¹ The explanation of this formula is given at the end of the chapter. The rule is—Divide the product of the two resistances by their sum.

The resistance of the entire circuit—

Battery	10 ohms.
Line	80 „
Instrument and fault	6·6 „

Total	<u>96·6 ohms.</u>
-----------------	-------------------

The current leaving the battery $\frac{1,000}{96·6} = 10·35$ nearly.

The two circuits at the fault having resistances of 20 ohms and 10 ohms, are in the proportion of 2 to 1, so that if the current divides into three parts, two parts will pass through the instrument; and the strength of the signals will be $\frac{10·35 \times 2}{3} = 6·9$ parts, instead of 10.

Third Case.—The fault at the sending station A. The two circuits beyond the fault will be:—

1. By the instrument and line, 90 ohms.
2. By the fault, 20 ohms.

Their joint resistance $\frac{90 \times 20}{90 + 20} = 16$ ohms, nearly.

Add battery 10 „ „

The total resistance will be only 26 ohms.

Current leaving battery $\frac{1,000}{26} = 38$.

The two circuits beyond the fault are in the proportion of 2 to 9, and $\frac{38 \times 2}{11} = 6·9$, will be the strength of the signals, instead of 10.

Fourth Case.—The fault 20 ohms from A.

60 + 10 = 70 ohms, line and instrument,
20 ohms fault,

are the two circuits between which the current will divide, and $\frac{70 \times 20}{70 + 20} = 15·5$ their joint resistance.

Entire resistance of circuit—

Battery	10 ohms.
Wire to fault	20 „
Beyond fault	15.5 „

Total 45.5 ohms.

Current leaving battery $\frac{1,000}{45.5} = 21.7$ nearly, and

$\frac{21.7 \times 2}{9} = 4.8$ nearly, the strength of signals.

Fifth Case.—The fault 20 ohms from B, its resistance 20 ohms.

20 + 10 ohms, line and instrument.

$\frac{20 \times 30}{20 + 30} = 12$ joint resistance.

Total resistance—

Battery	10 ohms.
Wire to fault	60 „
Beyond fault	12 „

Total 82 ohms.

The current leaving the battery $\frac{1,000}{82} = 12.2$ nearly, and

$\frac{12.2 \times 2}{5} = 4.8$ nearly, the strength of signals.

Thus, on a circuit consisting of—

Line-wire of	80 ohms resistance .
Instrument	10 „
Battery	10 „

with an electromotive force of 1,000,

The strength of signals, when the line is perfect, will be 10.0 parts.

When a fault of 20 ohms' resistance is in the centre 4.4 „

The same fault 20 ohms from receiving station . . 4.8 „

„ „ 20 ohms from sending station . . . 4.8 „

„ „ at the receiving station 6.9 „

„ „ at the sending station 6.9 „

Thus, the effect of a fault is greatest when in the centre of such a line.

224. The following formula, from Gavarret's excellent work on the Telegraph, will be found more convenient for these calculations. It gives the effective current, or the strength of the signals:—

1. Call the resistance of the line between the sending station and the fault, including the battery and apparatus, R.
2. Call the resistance of the line beyond the fault, including the receiving apparatus, r.
3. And the resistance of the fault itself, f.
4. Let the electromotive force of the battery be E.

5. Multiply R by r.

Multiply R by f.

Multiply r by f.

Add the three products together.

Multiply f by E, divide this product by the sum of the three previous products, the quotient will be the strength of the signal at the receiving station.

Expressed algebraically, the formula reads thus:—

$$\frac{E f}{R r + R f + r f} = \text{strength of signals.}$$

The first case will be calculated thus:

$$R = 50. \quad r = 50. \quad f = 20. \quad E = 1000.$$

$$50 \times 50 = 2,500$$

$$50 \times 20 = 1,000$$

$$20 \times 20 = 1,000$$

$$\underline{4,500}$$

and $20 \times 1,000 = 20,000$, which divided by 4,500 gives 4.4 as the strength of the received signals.

In the fourth case, $R = 30, r = 70, f = 20, E = 1,000$.

$$1,000 \times 20$$

$$\underline{30 \times 70 + 30 \times 20 + 70 \times 20} = 4.8$$

In the fifth case, $R = 70, r = 30, f = 20, E = 1,000$.

$$1,000 \times 20$$

$$\underline{70 \times 30 + 70 \times 20 + 30 \times 20} = 4.8$$

225. It will be seen that the values of R and r in the two last calculations are transposed. Thus, when the resistance of

the battery is equal to that of the receiving instrument, a fault arising at a given distance from the sending end of the line will have an effect on the signals equal to that of the same fault at an equal distance from the receiving end.

Both stations will be equally affected by it.

But, practically, as the battery of a long circuit consists of many cells, it offers much more resistance than the instrument, and therefore the centre of the *line* will not be the centre of the *circuit*, which comprises not only the line-wire, but the battery and instrument. The effect of a fault on signals will therefore be greatest when nearest the *sending* station, thus :

Take a case in which an earth of 10 ohms' resistance occurs 5 ohms from A, and 115 ohms from B (Fig. 54): the resistance

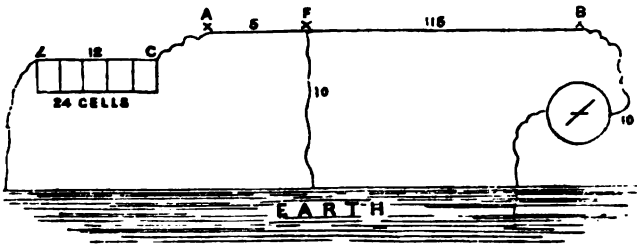


FIG. 54.

of the instrument or galvanometer being 10 ohms, of the battery of 24 cells 12 ohms, and the electromotive force 10,000.

When A sends a signal from 24 cells,

$$E = 10,000, R = 17, r = 125, f = 10,$$

the effective current received at B will be

$$\frac{10,000 \times 10}{17 \times 125 + 17 \times 10 + 125 \times 10} = 28.$$

When B sends,

$$E = 10,000, R = 127, r = 15, f = 10.$$

Effective current received at A,

$$\frac{10,000 \times 10}{127 \times 15 + 127 \times 10 + 15 \times 10} = 30.$$

Now calculate the effect of increased battery power, say 48 cells.

A sending—

E will be doubled = 20,000 ; the battery resistance is also doubled.

$$R = \text{battery } 24 + \text{line } 5 = 29.$$

$$r = \text{instrument } 10 + \text{line } 115 = 125.$$

$$f = \text{as before } = 10.$$

$$\text{Effective current, } \frac{20,000 \times 10}{29 \times 125 + 29 \times 10 + 125 \times 10} = 38.$$

B sending—

$$E = 20,000.$$

$$R = \text{battery } 24 + \text{line } 115 = 139.$$

$$r = \text{instrument } 10 + \text{line } 5 = 15.$$

$$f = \text{fault } = 10.$$

$$\text{Effective current, } \frac{20,000 \times 10}{139 \times 15 + 139 \times 10 + 15 \times 10} = 55.$$

Here, as the resistance of the battery increases, the difference in the effect of the fault on signals received at the two stations increases also.

Double the size of the plates, halving the resistance.

A sending—

$$E = 20,000.$$

$$R = \text{line } 5 + \text{battery } 12 = 17.$$

$$r = \text{line } 115 + \text{instrument } 10 = 125.$$

$$f = 10.$$

The effective force is 56.

B sending—

$$E = 20,000.$$

$$R = \text{line } 115 + \text{battery } 12 = 127.$$

$$r = \text{line } 5 + \text{instrument } 10 = 15.$$

$$f = 10.$$

The effective current is 60.

Here the effective current is just double that of 24 cells of the smaller size. The battery resistance having been halved, the total resistance is the same as with 24 cells, while the electromotive force is doubled.

226. To sum up the foregoing calculations and extend them in a tabular form :—

If on a wire, whose resistance is 120 ohms, there be a fault

offering a resistance of 10 ohms, situated 5 ohms from the end A; then, if the recording apparatus have a resistance of 10 ohms, the battery of $\frac{1}{2}$ ohm per cell, and if the electromotive force (E) be 10,000 per trough of 24 cells—the effect of the fault on the current received at each terminal station is as follows:—

No. of cells.	Resistance of Battery, in ohms.	E.	Strength of Signals received at A near the fault.	Strength of Signals received at B distant from the fault.
24 small	12	10,000	30	28
48 „	24	20,000	55	38
96 „	48	40,000	94	47
192 „	96	80,000	147	53
24 double	6	10,000	81	36
48 „	12	20,000	60	56
48 treble	8	20,000	61	66 ¹
96 double	24	40,000	110	77

The current received from 24 cells, when the line is perfect, is 70, and from 48 cells 130.

In France, where the resistance of the coil is extremely high, the station *nearest* a fault is most affected by it; hence their works on practical telegraphy appear to contradict what has just been stated.

227. When there are several faults, the calculation is much more difficult; with two faults, the law is this:

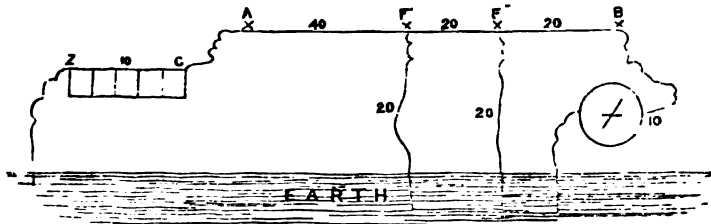


FIG. 55.

Taking the same circuit as in the former cases, with two faults,

¹ This case is an exception to the general rule that the signals received at the station farthest from the fault are more enfeebled than those received at the station nearest it. The reason is, that in this case only is the resistance of the battery less than that of the coil of the apparatus.

F' and F'', each of 20 ohms' resistance, the first 40 ohms from A, the second 20 ohms from B.

When the line is perfect the resistance will be 100, and the current $\frac{1,000}{100} = 10$, as before.

With one fault at F' the resistance $\frac{50 \times 20}{50 + 20} = 14.2 + 50 = 64.2$.

With one fault at F'' „ $\frac{30 \times 20}{30 + 20} = 12 + 70 = 82.0$.

With both faults—

Resistance beyond F'' = 12 ohms.

„ between F' and F'' . = 20 „

Total resistance beyond F' . . 32 ohms.

The joint resistance of F' and the circuits beyond it are

$$\frac{32 \times 20}{32 + 20} = \frac{640}{52} = 12.3$$

Add the battery and the line from A to F' 50.0

Total new resistance 62.3 ohms.

Current leaving the battery $\frac{1,000}{62.3} = 16$ parts instead of 10.

This current will divide at F' between the wire and the fault, in the inverse proportion of the resistances 20 and 32, and 6.1 parts will go towards B; this will split again at F'' between the two resistances 20 and 30, and 2.4 parts will reach the receiving apparatus.

228. Occasionally, when insulation is very defective, a wire will test alike whether disconnected at the distant end or not, yet sufficient current will reach the instrument to give readable signals.

Take a circuit of 40 ohms, and let there be a fault of two ohms' resistance in its centre—

$$\frac{20 \times 2}{20 + 2} = \frac{40}{22} = 1.8 \text{ will be the resistance beyond the fault.}$$

Force of battery . 1000,
Resistance of circuit $1.8 + 20$ = 45.8, the current passing out to line.

$$\frac{45.8 \times 2}{22} = 4.1, \text{ current reaching the instrument.}$$

If the wire be disconnected at B, the total resistance of the circuit will be 22 ohms instead of 21·8, and the current passing out to line 45·4, instead of 45·8, or almost exactly the same as when not disconnected.

229. The laws of *derived currents*, or faults, as already explained, will enable us to calculate the effect of connecting instruments, so as to divide a current between them, thus:—

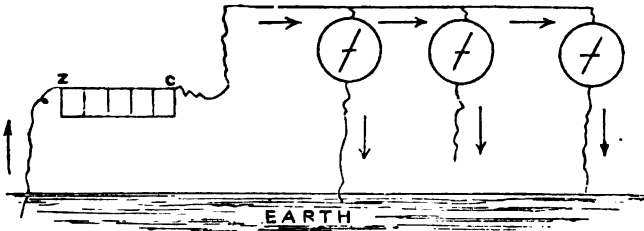


FIG. 56.

The same law will enable us to explain how it is that there is no appreciable difference in the signals, whether the needles of a double-needle instrument are worked singly or together, although the effect of working both at once is precisely the same as establishing an earth of equal resistance to the entire circuit excepting the battery, close to the sending station.

Take the line of 70 ohms, with battery and instruments each of 10 ohms' resistance, and force of battery 1,000.

When one needle only is used, $\frac{1,000}{100} = 10$ will be the signal.

When both are used, the current will divide thus:—

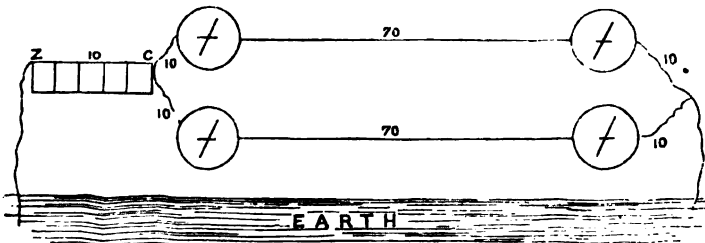


FIG. 57.

And we have $\frac{90 \times 90}{90 + 90} = 45$ ohms as the joint resistance of the two wires.

Adding the battery 10 ohms, $\frac{1,000}{55} = 18$ will be the current passing out to line, and 9 the signal instead of 10. If the battery had less resistance, the difference of signal would be less; and if it were nothing, the signal would not be affected at all. But the battery, being harder worked, would get weak much more quickly.

230. Thus, two or more wires of similar resistance can be worked from the same large battery, provided they be well insulated, and that the current be sent on each in the same direction; for if the copper be put to earth on one circuit, while the zinc is to earth on another, the battery will be on "short circuit." Double sets of batteries, one for the positive and the other for the negative current, allow of reversals.

A great objection to the method is, that a battery fault affects all the circuits connected with it, and a line fault renders the current very variable, as may readily be seen on a double-needle circuit. The system has, however, been extensively employed on the Continent, is universal in the United States, and is successfully worked in London upon several groups of the short metropolitan circuits.

At the central office in Amsterdam, where single (unreversed) currents are used, the battery consists of zinc-carbon and dilute sulphuric acid. The terminal zinc is put to earth, and the instrument wires of the shortest circuits are connected to the 20th carbon, so that they are worked with a tension of 20 cells: others are connected at the 40th, 50th, and 80th, and the longest circuits at the 100th, or terminal carbon.

From the 100th to the 81st, inclusive, the cells are arranged in single series; from the 80th to the 51st three series are placed side by side; four series from the 50th to the 41st; from the 40th to the 21st there are five sets side by side, and the 20 nearest the zinc end, which are used in the shortest lines, consist of six series.

The local battery is 45 similar cells arranged in three series of 15 cells side by side.

From these batteries forty circuits are worked, and, it is said, with success.

In the United States the Grove or Bunsen battery, which has a very small resistance, is used; and it is stated by one of the leading American electricians that it was found on a very wet day, if a circuit of 100 miles was connected to 60 cells of Bunsen, the addition of three similar wires reduced the current on the first one 12 per cent. He adds, that it is a common practice to attach as many as eight wires to such a battery, which in the case named would have reduced the current above 25 per cent.

He also states that, in the opinion of many of those best qualified to judge, it would be more economical and more efficacious to use a separate set of Daniell for each long circuit.

231. The law that a current *splits* or divides according to the resistances of the several paths open to it, enables us to explain a method which has been proposed for signalling across rivers without wires.

Large copper plates are placed in the water at A, B, E, and D (Fig. 58), connected by insulated wires. Two paths are then open

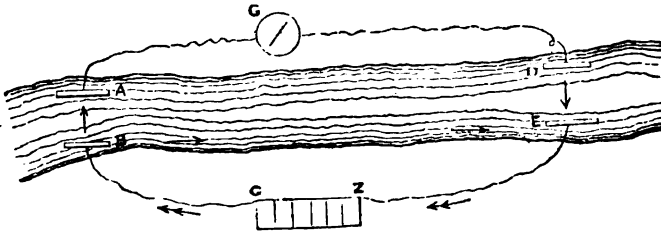


FIG. 58.

to the current from the battery CZ; CBEZ following the course of the river-bank, and CBAGDEZ crossing the stream, passing through the wire AD and the galvanometer G. In order that sufficient current to produce a signal shall pass through G, it is necessary that the distance BE along the bank should be considerably greater than double the breadth of the river. We are not aware that this method has been adopted in practice.

The same explanation applies to the singular case, which occasionally occurs, in which signals pass through a broken wire, the ends of which lie on the ground at a short distance from each other.

232. The foregoing calculations show that increasing the size of the plates, rather than increasing their number beyond a certain limit, is theoretically the best method of providing for the loss of current arising from defects in insulation. Practice fully confirms the theory.

To give examples: Mr. Varley records the following observations made on the London-Bristol circuit, at a time when the insulation was far less perfect than at present, and when sand batteries were used, which are much more quickly exhausted than the batteries now employed, so that the effects are in some respects exaggerated, although they illustrate the principle admirably.

The number of cells usually employed was seventy-two, the plates measuring three inches by four. On a very wet day Bristol was unable to read. The batteries were tested for resistance with a thick wire galvanometer (quantity detector), and gave $40^{\circ 1}$ on short circuit. The signals were not legible until the number of cells had been quadrupled. After an hour they again failed. The batteries now showed but 25° , instead of 40° , having nearly doubled in resistance; and a fine wire galvanometer placed in the line-circuit indicated 14° as the strength of the current flowing from battery to line.

The 288 cells were then formed into two parallel series of 144 cells each, the copper poles of each set being connected to the copper terminal of the instrument and the two zinc poles to the zinc terminal of the instrument. The battery thus arranged was equivalent to 144 cells of double the usual surface, so that its *resistance* was no greater than the original series of 72 cells, while its electromotive force was twice as great.

When this battery was joined to the line the line-wire galvanometer indicated 20° , and Bristol read well. When the

¹ The resistance of the batteries in ohms is not known. The experiment was made before the system of testing in units had been introduced.

battery was again joined up in one series of 288 cells, Bristol could not read. The resistance of each cell was probably 20 ohms, and that of the line and apparatus about 1,900. The total resistance when 72 cells were used would then be about 3,340 ohms, and with 288 cells in single series 7,660 ohms. But this resistance was doubled by the exhaustion of the exciting liquid, after an hour's work, so that the extra resistance would have balanced the increase in *power* from the greater number of cells, and have prevented an improvement in signals, even if the electromotive force of the cells had not been reduced.

Again: the signals upon the same circuit having failed on a wet day, 144 cells were added for *tension*, and communication was restored. But after two hours the signals again failed, and when the original 72 cells were tested for resistance, they gave 3° only. Upon removing them from the series, leaving the 144 cells which had been added, Bristol read well. Thus the increasing the electromotive force of the series exhausted the defective set more quickly than would have otherwise happened.

The following results were obtained by Mr. C. V. Walker, in actual experiment, on a very bad line of $5\frac{1}{2}$ miles, including a defective tunnel. The current received at the distant end was:—

From 24 cells, ordinary size	.	.	10
„ 24 „ double „	.	.	24
„ 24 „ treble „	.	.	27
„ 24 „ four-fold „	.	.	30
„ 24 „ five-fold „	.	.	31
„ 24 „ six-fold „	.	.	32
„ 48 „ ordinary „	.	.	19
„ 48 „ double „	.	.	37
„ 48 „ treble „	.	.	46
„ 72 „ ordinary „	.	.	21
„ 72 „ double „	.	.	43
„ 96 „ ordinary „	.	.	23
„ 120 „ ordinary „	.	.	26

233. There are other reasons against unduly increasing the number of cells of a battery when the line-resistance is lessened by bad insulation. It exhausts the battery very much more quickly, because of the increased action due to increased electromotive force, and it is much less economical.

The chemical action, in each cell of a series, is precisely equal and proportional to the current produced (59). It is evident, therefore, that if we can obtain the same effect by a certain number of large cells as by twice the number one-half the size, the consumption of zinc and sulphate of copper will be reduced one-half.

234. However well a line may be insulated, there is an enormous difference between wet and dry weather; the insulation of the best lines falls very low (comparatively speaking) in heavy rain.

The average insulation resistance per mile of a circuit of 280 miles of No. 4 wire, without intermediate stations, was found to be—

	Ohms.
In moderately fine weather	13,700,000
Lowest insulation in wet weather while working well	192,000
Insulation at which communication became difficult	182,000
Resistance of the wire itself	2,260

It may be that the 280 miles of wire would work with an average insulation of 182,000, if the leakage were uniformly distributed; that is, if one part of the line were as good as another. Such a condition is, however, never attained in practice, and, as will easily be understood, there is a great difficulty, when communication is slow and business delayed, in learning precisely the condition of each portion of the line. In the case of a somewhat shorter and better insulated line the highest recorded insulation per mile was—

	Ohms.
In fine weather	78,750,000
The lowest in wet weather while working well . .	131,000
The circuit was not stopped at	91,900

This last circuit is never seriously affected by weather: the

insulation never falls below the working-point, unless in case of accident; and, generally speaking, no circuit, insulated with double-shed brown-ware, not exceeding 400 miles, even if not of larger gauge than No. 8, is ever stopped by this cause except it run for a considerable distance near the sea; and not even when near the sea unless some of the insulators are cracked.

NOTE.

235. *Determination of the joint resistance of two or more circuits between which the current divides, as in the case of a fault, a shunt, or two circuits worked by the same batteries (230).*

When a current splits between two or more conductors, it divides proportionally to their resistance. If the two conductors are precisely alike, it divides equally; if they are similar, save in length, then the current divides between them in the inverse ratio of their lengths.

Let R and r be the resistances of the two circuits, C and c their conductibility; the two united will have a conductibility x equal to $C + c$, that is, equal to $\frac{1}{R} + \frac{1}{r}$ (resistance being the converse or *reciprocal* of conductibility.)

Then the conductibility $x = \frac{1}{R} + \frac{1}{r} = \frac{R + r}{R r}$; the resistance being the reciprocal $\frac{R r}{R + r}$. That is, the resistance of the two circuits, when connected, is equal to the product of their separate resistances divided by their sum.

The joint resistance of any number of conductors, connected side by side or in *multiple arc*, may be found by adding together the *reciprocals* of their respective resistances and finding the reciprocal of the result.

The *reciprocal* of any number is the fraction obtained by dividing unity by that number; and that of any fraction is the fraction itself inverted. Thus the reciprocal of 2 is $\frac{1}{2}$ or $\cdot 5$; and, conversely, the reciprocal of $\cdot 5$ or $\frac{1}{2}$ is 2; the reciprocal of $\frac{2}{3}$ is $\frac{3}{2}$.

Let it be required to find the joint resistances of three wires, measuring 20, 30, and 12 ohms respectively.

By the first-named method, the joint resistance of the first two is found thus $\frac{20 \times 30}{20 + 30} = 12$; and then the resistance of this pair and the third wire $\frac{12 \times 12}{12 + 12} = 6$.

By the second method, the reciprocal of 20 is 0.50

30 is 0.33

12 is 0.83

which added together = 1.66

the reciprocal of which is 6.

This operation is equivalent to the addition of the following fractions, representing the *conductibility* of the several wires, and taking the reciprocal of, or inverting, the fraction representing their sum.—For example, $\frac{1}{20} + \frac{1}{30} + \frac{1}{12} = \frac{1}{6}$ which inverted is $\frac{6}{1}$ or 6.

PART VII.

THE CONSTRUCTION OF A LINE OF TELEGRAPH.

236. In order to establish communication between two places it is necessary to erect a wire of sufficient conductibility, and to insulate it sufficiently well. A good earth-connection must be provided at the terminal stations, and a circuit formed, including the earth, the apparatus, the line-wire, the apparatus at the distant station, and the earth again. Intermediate stations are introduced by cutting the wire, and placing the instrument between the divided ends.

237. Leaving first-cost out of consideration, it is better to use suspended rather than buried wires, because of the liability of gutta-percha and india-rubber to deteriorate, the expense of repairing faults, and the retardation of signals consequent upon the greater inductive capacity (151) of wires laid underground. Short lengths of buried wire alternating with suspended wire should be avoided as much as possible, because the deterioration of percha is rapid where exposed to air and light, and it must necessarily be exposed at the points where the two systems join.

238. The preparation of percha and rubber, and especially the method of joining the several pieces, have been so greatly improved since the failure of the extensive systems of buried wires in Prussia and in England, that long subterranean lines are now quite practicable, where special circumstances make them necessary.

No instance has occurred of percha having deteriorated *when placed under water*. In the sea it appears to be indestructible. The experience of india-rubber is not so satisfactory.

239. It is better and cheaper, in the country, to use iron wires carried on poles over tunnels, than covered wires through them. In towns, however, if there are many wires, or if the circuits are long and important, it is better to carry them under the streets than over the houses. In the first case, there is little difficulty in planting the poles, and insulation is good in the open country; in the second case, open wires rust quickly: their insulation is bad because of smoke, and it is not easy to find permanent positions for the supports.

240. For poles the best foreign timber is the most durable, but its price precludes its use in England, except where a more slightly appearance or extra strength is required. English larch, from thirty to forty years' growth, cut close to the ground so as to obtain the "natural butt" of the tree, having its rings close, and containing a fair proportion of heart-wood, if felled in the winter and well seasoned, is very suitable; but, if possible, poles should be prepared with some antiseptic, such as creosote or copper sulphate. The poles, if unprepared, should be barked and stacked in such a manner as to allow a free circulation of air among them, the lowest tier being raised several inches from the ground. They should be protected from the sun, so as not to dry too quickly, or they will split.

If the bark is allowed to remain on, splitting will be prevented, but they will be liable to be attacked by boring worms and other insects; and the sap, when prevented from drying out quickly, ferments, and forms the germs of decay.

The butt ends should be well *roasted* over a slow fire. From the bottom to a foot above the intended ground line should be slightly charred, and tarred when hot, with a mixture of four parts of gas-tar (boiled with powdered *quick-lime*, to expel the water and ammonia) and one of Stockholm tar. When set on the line, they should be allowed to remain for three or four months to dry thoroughly, before they are painted, which should not be done except in dry weather.

If it be impossible to procure seasoned timber, the butts should be charred and baked, *but not tarred*; for coating green timber with tar or paint prevents its drying, and causes it to decay. When the timber has become well seasoned, the soil

may be removed to a depth of at least a foot around the bottoms of the poles; and when this part has become dry, the tarring and painting may be proceeded with.

It is difficult to creosote larch unless it is perfectly dry. Round Baltic poles creosoted are very suitable, but unless prepared they will not last as long as seasoned larch.

For lines of ten wires, or less, a diameter of five inches at top is sufficient: if more than ten wires, six inches. The greater the distance from one another at which the poles are set, the stronger must be the timber.

241. On railways, so far as possible, the wires must be placed within sight from the trains, so that they may be readily inspected. Bearing this in mind, the poles should be set at the greatest possible distance from the metals, so that if a pole be broken it shall fall clear of the line. The holes should not be less than five feet deep.

242. When poles fall across the rails, the platelayers are compelled to cut the wires to clear the line, so that they *run back* a considerable distance, increasing the damage six-fold. It is better, therefore, on very important circuits, that they be *terminated* at each end of large station-yards, where the poles cannot be placed free from the lines of rails; so that if an accident occur, and the wires be cut by the workmen, they may not run back beyond the terminal poles.

Too much care cannot be taken when the wires of a railway cross a public road, especially when they pass over a bridge by which the road crosses the railway. It is better in turnpike-roads to place a pole on each side of the bridge, and to double bind and solder the wires to the insulators at these poles, and double bind, without soldering, at three or four poles on each side; so that the breaking of a wire near the spot shall not by any chance cause it to drop so low across the road as to endanger the traffic. Each wire should be *guarded*, to provide against danger from broken insulators.

However desirable it may be to set poles in a straight line upon railways, it is objectionable doing so on roads when they must be crossed either wholly or partially by the wire. Roads should never be crossed by the wire unless impera-

tively necessary. Every such crossing is an indefinite source of risk to persons travelling on the road either in snow-storms, frosts, or gales.

243. Over tunnels or bridges, in places which are not within sight, or where there would be more than ordinary difficulty in executing repairs, the work should be unusually strong, the best wire used, the greater distance given between wire and wire, so as to make such portions less liable to interruption. In such places, it is also desirable to use iron hoods to protect the insulators from damage by stones, and to fix guards to catch the wires, should they become detached by the breaking of the insulators or bindings. On curves, also, the wires should be guarded, especially so on the inside of the curve.

244. The smaller the number of poles to the mile, the better will be the insulation, and the less the cost; but the greater the liability to accident, and the greater the difficulty of making repairs.

Experience has shown, that for a railway telegraph of more than about eight wires, there should not be less than twenty poles to the mile on straight parts of the line, and a greater number on curves, dependent on the radius (or sharpness) of the curve, and on the direction of the strain. When the poles are set on the outside of the curve, the strain tends to pull them towards the rails, and if a wire break loose, it will hang nearer the trains than it did when in its place; so that there is a greater chance of accident to the train than when the poles are on the *inside* of the curve, and would fall from the metals. On branch-lines, where not more than four wires will be required, sixteen poles per mile, or even fewer, are sufficient, provided they can be set so far back that if they fall they shall clear the rails. On roads the number of poles is considerably greater.

It is better, if possible, to allow the earth time to consolidate round the poles before the wires are fixed, that their strain may not pull the poles out of place.

245. The pressure of the wind on the poles and wires is *very great* in a gale; it is, therefore, desirable to erect the telegraph on the *lee side* of the railway, where it may be sheltered from the prevailing winds. Where the line runs north and south, the

east side should always be chosen. In cuttings, where the wires are sheltered, although the poles are necessarily set near the rails, the risk is much less than on embankments, where the wires are fully exposed, and where a side-wind will blow them across the line, sometimes even to a distance equal to their dip or "*sag*." When the span is long, and the wires consequently slack, the distance from the rails must therefore be correspondingly greater.

246. The poles must always be made to lean back slightly against the strain of the curves, and should be stayed so as to oppose the strain. On straight lines and slight curves, where exposed to the wind, double stays, to prevent their moving either way, are required; for if one stay only is used, the poles will spring back during the lulls of a gale blowing from the side opposite to the stays, and the wires will not only be made to swing into contact, but the stay will be loosened, or even broken. On sharp curves the strain of the wire acts as a stay in one direction. Each pole must be made as stiff as possible, in order to be perfectly secure. The earth must be well rammed, especially at the top and bottom of the hole; and if stones can be obtained, they may be so placed as to give the pole a firm thrust against the undisturbed part of the soil.

A peculiar tool is used in Spain for digging holes. A segment of a disc (about one-sixth) is fixed on the end of a staff six or seven feet long, and at right-angles to it; the disc has a ledge or rim on one side and at the end. If this tool is pressed against loose earth and turned a quarter round, it takes up a portion which the ledge prevents from falling off. To dig a hole two men are employed, one with the tool, the other with a crowbar to loosen the earth. By this method no more earth is removed than is just enough to receive the pole, and it is, in consequence, more firmly fixed than by the ordinary method. It succeeds very well in alluvial soil, gravel, or even in clay, but not at all in peaty or sandy soil. It can be used in a hole filled with water.

In America the pick and shovel are seldom used. Holes are dug with a crowbar, and a spoon shaped like a very shallow funnel.

A boring tool has been used with advantage, but its use is more laborious than that of the spoon and bar.

247. However well rammed, stays are apt to draw and become loose in light soil. When large stones cannot be found, an iron stay-anchor, or a piece of an old pole, sound and well charred, can be used. And in all cases, most especially in sand, the hole should be *undercut*, so that the stone or log may have a pull against the solid undisturbed earth.

Wire stays are apt to rust at the surface of the ground, and should therefore be well tarred or painted; an iron rod, projecting a foot or two above the soil, to which a wire can be fastened, is to be preferred. A few links of chain may be attached to the stay-wire, and the rod may terminate in a hook; this is an easy method of tightening the stay. For terminal poles, or poles having great strains, rods or stranded wire should always be used, or it is very difficult to make a stay of several wires, in such a manner as to distribute the strain equally between all the wires of which it is composed. As twisted or stranded wires expose a larger surface than rods, they rust more quickly.

When a stay is fixed to the top of a pole on which there is much strain, the pole bends below the stay; if the stay is fixed below the wire, the pole bends above. In such cases the stay should be placed in the centre of the strains, or it may consist of two branches, one fixed above and the other below the wires, uniting into one a few feet below the lowest wire.

248. In soft soil, and generally where great strength is required, struts are to be preferred to stays, as they compress instead of lifting the earth, which, after long-continued rain, becomes very soft and yielding; but whenever a strut is used, it must be remembered that the strain of the wire tends to bend the pole below the strut—the point of the latter acting as a “purchase” or fulcrum; and again, that the strut itself is liable to bend. These inconveniences are met by tying or framing the two together.

The strain of the wires on a terminal post tends to push the strut into the ground. A flat stone, or piece of timber, should therefore be placed under the foot of the strut, to give it an en-

larged bearing. The strain will also tend to turn the pole upon the fulcrum formed by the upper extremity of the strut, so as to lift its heel out of the ground. A sleeper, or log, well backed up with large stones, should therefore be so placed as to give the pole a solid thrust against the firm soil.

249. Where neither stays nor struts can be fixed, two poles may be set side by side and bolted together; or they may be arranged as the letter A, a broad bearing against the soil being given by sleepers laid horizontally.

When a large number of wires are required, they are carried on two sets of poles, framed together so as to support one another. There is, however, nothing special in these methods of construction which will not be obvious to any skilled workman.

Poles exposed to a great strain may with advantage be "trussed" like a girder with a rod or stranded wire. The strain of the line-wires tends to render the opposite side of the pole convex, but it cannot bend without stretching the truss-wire. The truss should always be fixed round the bottom of the pole, for if fixed at the ground-line it will give the pole a tendency to break off at that point.

250. In deciding on the strength of a line, it must not be forgotten that on very rare occasions, when the air near the ground is rather colder than above, and when snow falls at a temperature a little above freezing, it adheres to the wires, and, if the downfall continue, will coat them to a sufficient thickness to break them and the poles. It would seem that no *practicable* strength of construction will enable a line to resist the combined effect of a coating of snow followed by a gale. In Holland the mists freeze upon the wires, giving them a coating of several inches diameter, which splits when the sun breaks out, forming, as it were, splinters, which interlace and connect the whole of the wires.

Where there are heavy falls of snow, sufficient room must be left between the insulator and pole to prevent the snow lodging there, and the supports should be specially arranged with the same object.

251. Each pole should be furnished with an *earth-wire*, or contact-conductor (219), which should be put on the pole

before it is fixed, and be formed into a flat coil attached to the foot of the pole, so as to expose as large a surface as possible to the earth.

It is very important this wire should make good earth. When this cannot be effected, the conductor should be dispensed with.

252. WIRE.—For ordinary purposes, galvanized iron wire 170 mils. diameter is used, for short lines 125 mils., and for long and important circuits 240 mils.

These gauges are very nearly the same as those employed in France—4, 3 and 5 millimetres.

The smaller the wire, the more care is needed in insulation, for an increased resistance in the wire virtually adds to the length of the circuit. It has been found that with wires equal in insulation, a circuit which *works badly* with a 170 will *work well* with 240 mils. line-wire. 125 wire rusts away very quickly in smoky places; it is sometimes worn through by chafing at insulators, and is apt to stretch at the points of support if the spans are too long.

253. Wire, for general use, should be soft, and capable of stretching 18 to 20 per cent. before breaking. For *very* long spans, harder wire, which does not stretch so readily, is preferred. The soft wire should be capable of being bent at right angles several times backward and forward without breaking, so that joints may be made securely, and the breaking strain should not be lower, for 170 mils., than 1,300 lb. In France, annealed charcoal wire is used; the 4 millimetres is required to stand a *sudden* strain of 968 lb. (440 kilos.), and the three millimetres, 550 lb. (250 kilos.). It must bear bending at right angles in a vice, first one way then the other, four times; and must stand wrapping round itself. Charcoal-wire is of a better quality, and more expensive than the wire generally used in England.

The longer a bundle of wire is, the better, provided it does not exceed a weight which is convenient to handle, 112 to 120 lb., because it is desirable to have as few joints as possible, as they are apt to cause contacts.

When the wind is high the wires are blown together, and if there be no joint, or other inequality, by which one may

catch and cling to the other, they fall apart again; but where there are joints they hook themselves together, and remain in contact until the line-man separates them, so that it is desirable never to make a joint except within ten feet of a pole, where the wires cannot blow into contact.

254. Common wire is made in somewhat short lengths, which are welded together. The welds are very often defective: weak places are also caused by dirt or cinder in the iron, and by splits in the rod, and it is most desirable to find out and remove these causes of accident beforehand; for when wires are broken by contraction in frosty weather, or by a gale, the failures *always* occur at these weak places, or where the wire has been chafed by an insulator. The wire should therefore be strained till it stretches after it is laid out on the line, in order to break out the defects. This process will also remove the wrinkles and irregularities, and not only makes the wire look much better, but renders it less liable to be set swinging by the wind, and, should it be put in motion, less liable to catch and remain in contact. If a straining machine is not at hand, let it be drawn as tight as possible by ropes and blocks, and then pulled at the centre of its length at right angles till it stretches. It will be found to have lost its spring, and can be so easily handled that it is technically said to be *killed*.

Permanent contact is sometimes caused by the clinging together of the slight bends and irregularities which occur in unstretched wire; these are removed by the killing, and, indeed it seems that killed wire is scarcely acted upon by the wind, for it may be seen comparatively still when others on the same poles, which retain their irregularities, are swinging to and fro.

255. Great attention is now paid to the manufacture of telegraph wire. The best quality is now drawn in lengths weighing 80 or even 120 lb., *without welds*, and is *killed* or stretched about 2 per cent. by the manufacturers, by passing over two drums, one of which is slightly larger than the other. It is also made to pass under and over pulleys arranged in a zigzag form, in order to open and break any *splits* that may exist; and lastly, it is carefully tested for ductility and breaking strains.

The result of tests for ductility and breaking strain vary very much with the method in which the tests are made.

When a piece of wire is clipped between two vices for testing, the sharp edges of their jaws must be rounded off, or they will cut the wire and cause it to break close to the vice. If the wire is fastened to a hook instead of to a vice, it must clip the hook closely; and if a loop or fastening is made by twisting, it will certainly break—it should be bound like a Britannia joint.

256. Two methods of testing have been employed: in one the wire must bear a certain degree of elongation without breaking; and in the other a certain number of twists in a given length.

The percentage of elongation in a given sample is affected, (A) by the length of the piece tested, and (B) by the time occupied by the test.

257. (A) *Length*.—It is impossible to manufacture wire perfectly uniform throughout, and therefore the longer the piece tested the greater the chance of its containing a portion of low ductility.

For example.—75 tests of a coil of 165 mils. diameter gave the following means:—

Lengths of 10 inches stretched 19·5 per cent.				
„	120	„	„	12·7
A few tests of 100 yards		„	6·0	„

Again, two samples elongated equally well, stretching only 18 per cent. when tested in 10-inch pieces, although one of them was of a quality much superior to the other, judging by the way in which it *handled* during erection. Tested in longer pieces, the results were—

	No. 1.	No. 2.
Lengths of 10 feet stretched	12·0	9·0 per cent.
„ 100 yards „	5·5	4·5 „
But 10-inch lengths „	18·0	18·0 „

Here the testing longer pieces brought out clearly their relative qualities, which under the first test appeared identical.

But it is obviously impossible to test so long lengths as 100 yards, or even 100 feet. Ten feet give trustworthy results,

and 100 or even 50 inches will probably bring out those qualities which render a wire easy to handle during erection, and free from danger of breaking after erection: a 10-inch test is not trustworthy, except when made by very experienced persons.¹

When tested in lengths of 10 feet or more, wire frequently remains ductile, except immediately on either side a break, and will afterwards bear a higher strain in 10-inch pieces.

258. (B.) *Time*.—The percentage of elongation before breaking is (roughly) inversely as the time occupied by the test. Thus—

when *Time* was as 100 — 173 — 311.

Elongation „ 178 — 154 — 138.

When the test is made rapidly, as by a hydraulic stretching apparatus, the wire seems not to have *time to break* before it stretches, it may be that heat is developed by the strain, so as to soften the wire. When the test is made by direct weight, the sample will bear a heavier strain, if the weight is added gradually than if it is increased quickly. The wire breaks more readily if it is not allowed to complete the elongation due to each successive addition before the weight is increased.

259. The following are the means and extremes of 27 different samples tested in 10-in. lengths by the *hydraulic apparatus*:—

	170 Mils.		125 Mils.	
	Means.	Extremes.	Means.	Extremes.
Diameter before testing	0.151 in.	0.147 to 0.153 in.	0.115 in.	0.112 to 0.120 in.
„ after having been broken	0.140 in.	0.136 to 0.144 in.	0.106 in.	0.100 to 0.117 in.
Percentage of stretch before breaking	20	19 to 25	20	19 to 25
* Strain required to stretch the wire	672 lb.	600 to 750 lb.	505 lb.	400 to 600 lb.
Breaking strain	1318 lb.	1250 to 1440 lb.	776 lb.	740 to 850 lb.

* It seems to be difficult to ascertain the precise moment at which elongation commences.

The following are means of ten tests of wire of the same quality and from the same makers, tested in lengths of 33½ inches by *scale and weight*, adding 56 lb. at a time, gently and without jerk, and waiting until the wire had ceased to stretch

¹ It is not doubted that a 10-inch test has been valuable, but the object in devising a test is to make it, as far as may be possible, independent of experience in the observer—such a test, in fact, as any intelligent man can apply.

before adding more weight. These results are probably affected by the difference in the length tested :—

Percentage of stretch before breaking	11·2
Strain required to stretch the wire	904 lb.
Breaking strain	1,132 lb.

260. The *twist* test is not so much affected by time, it is independent of length ; the means of 100 trials in each of two different machines are :—

Speed	10·0	25·0
Number of twists	14·0	14·3

This test is made by gripping 6 inches between two vices and twisting it. The number of twists is shown by the spiral formed by a line drawn with ink along the wire before the trial.

261. The best qualities of wire, charcoal and “homogeneous” metal, bear the twist better than the elongation test.

Thus, comparing wire of similar gauge, 100 mils—

Ordinary wire—Elongation, 17·4 per cent.—Twists, in 6in., 12	
Charcoal ” 17·0 ” ” 18	

And again—

Ordinary 234 mils Elongation, 17·6 per cent. Twists, 10	
Homogeneous 253 ” ” 17·6 ” ” 13	

The number of twists wires of the same quality will bear is (roughly) inversely as their diameter. A wire of 253 mils bore 13 turns in 6 inches, this being an average of a large number of trials. The number of twists was calculated for other gauges, and compared with the results of experiment.

Diameter.	Total Number of Turns.	
	Actual.	Calculated.
Mils.		
253	13·0	13·0
207	15·2	15·9
146	24·9	22·5
77	38·7	42·7

262. Galvanized¹ wire must always be used for permanent work, no system of painting or varnishing the iron itself having been found to answer as well.

The French test the thickness of the zinc coating by dipping the wire in a solution of copper sulphate. The process is this: Dissolve one pound of copper sulphate in five pounds of water; plunge the wire into the solution; let it remain one minute, and then wipe it clean; repeat this process four times. If the wire appears black after the fourth immersion, it shows that the zinc has not been all removed, and that the galvanizing was well performed; but if it has a copper colour the iron has been exposed, proving that the zinc was too thin. The reason is that the acid of the sulphate leaves the copper for the zinc dissolves it, and leaves a black deposit of copper upon the wire; but when the zinc has been entirely dissolved away, and the copper is deposited on the *iron*, it bears its natural hue, just as when a knife is dipped into sulphate of copper.

263. Galvanizing does not seem materially to alter the breaking strain, but it has a decided effect upon the capacity of stretching. It slightly hardens the metal.

ORDINARY WIRE. 170 Mils.	Mean breaking strain.	Mean percentage of Stretch before breaking.
<i>No. 1 Sample.</i>		
Before galvanizing	11,38 lb.	18.75
After ,, ...	1,169 lb.	12.88
<i>No. 2 Sample.</i>		
Before galvanizing	1,090 lb.	19.39
After ,, ...	1,194 lb.	13.09
<i>No. 3 Sample.</i>		
Before galvanizing	1,107 lb.	20.66
After ,, ...	1,125 lb.	17.58

264. The zinc coating appears little the worse after twenty

¹ Galvanizing simply means coating with zinc. The term is apt to mislead, and it would be far better to use the word "zincing," for we call coating with tin, by an analogous process, tinning.

years' use, except in towns, in the vicinity of the sea, and where it is exposed to the steam and smoke from locomotives, as in tunnels, deep cuttings, and stations. In some places, wire of 170 mils will not last more than four years. So rapid is the corrosion in manufacturing towns, that it is useless employing a smaller size than 170 mils, unless it be specially protected.

265. Paint, or even gas-tar, protects galvanized wire where it adheres, but it cannot be applied in the manufactory so as not to be liable to be rubbed off here and there; and as no chain is stronger than its weakest point, so a wire which has rusted in spots where the paint has failed, might almost, if not quite as well, not have been painted at all.

It is a most expensive and tedious process to paint the wire after it has been fixed, but it is easily done during erection where the wire can be stretched along the lower part of the poles so as to be reached from the ground. Even if the work is done well, the paint is apt to be removed at the points of support, leaving the wire unprotected just at the very point where its full strength is most needed. Moreover, metal can only be effectually painted in dry weather when it is perfectly free from damp, and it is almost impossible to secure sufficient care in this respect from the workmen. The only plan which has really succeeded is that of running the wire through a paint or bituminous preparation, and immediately spinning around it cotton or hemp well saturated with the same compound. The fibre protects the coat of paint from abrasion, and at the same time causes it to adhere to the wire.

It is perfectly useless to attempt to stay the progress of rust after it has once commenced; for, however carefully the wire may be cleaned, the rust forms again under the paint and thrusts it off. If a speck of rust is seen on the tubes of the Britannia Bridge at Bangor, it is carefully chipped off with a cold chisel before it is re-painted.

When coated wire is used, it is necessary to wrap it with felt or metal at the points where it is fastened to the insulators. Thin lead (although certainly a dangerous metal for the purpose, because it sets up galvanic action) has proved effectual for many years, but the hemp with which the wire was covered in this

case was carefully re-tarred before the lead was wrapped round the wire. If any damaged places are seen after the wire is up, they must be carefully repaired, or the entire outlay will have been thrown away.

266. The lowest wire should be out of reach from the ground. The lighter wires should, as far as possible, be placed above the heavier ones, so as to give greater stability to the poles; and for the same reason, where arms are used, some of which carry two wires, and some four, the latter should be placed below. If wires of different gauges are fixed on the same poles, they are *very much more apt to get into contact* than wires of equal size, because they do not *keep time* with one another in swinging to and fro.

267. Wires are more apt to get into contact in the vertical than in the horizontal direction; hence there is an advantage in using arms differing about a foot in length, placed alternately. This arrangement has the advantage, also, that if a wire break from its support, it will generally fall clear of the one under it.

Fig. 60 shows the arrangement adopted in the postal telegraphs. The arms are alternately 24 and 33 inches long; the longer arm is frequently placed uppermost.

To give greater distance between wires, they should, when fixed each on a separate support, as a bracket, be placed alternately, not oppositely. The distance should increase with the span, and cannot be too great where there is sufficient room on the poles, for wires 17 inches apart are sometimes blown together in storms, even when tightly strained.

268. Where 20 poles are used to the mile, the distance should be not less than about 12 inches vertically, and 16 inches horizontally, so as to clear the poles well. It is better, as a rule, never to place more than two on an arm; because, when it carries more, it is more difficult to see faults and to repair

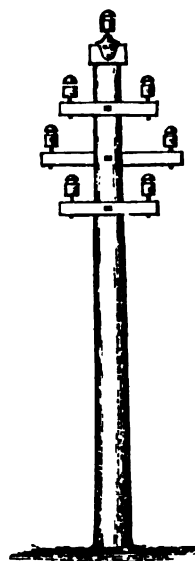


FIG. 60.

damages, especially to lift poles when blown down or broken. Snow also will more easily adhere, so as to cause a leakage from wire to wire.

It does not appear that the wires blow into contact much more frequently in long spans than in short ones, provided they are uniform in weight, tension, and distance. When they are properly "regulated," and all is symmetrical, they keep time one with another in their oscillations, but under other conditions they move occasionally in opposite or reverse directions, and in consequence meet. It is not desirable, therefore, to hang wires of different gauges side by side.

But long spans add to the causes of accident for another reason.

269. Wire is at all times apt to rub or wear because of the friction caused by the wind at its supports, unless they are very hard and smooth, or it is very firmly fixed either by binding or by its tension. It wears more upon a straight line than on a curve, and more when slack than when tight. Some wire which has been supported on brown-ware double cones (which are very hard and smooth) on poles set 30 to the mile, is not worn in the least degree, although much of it has been up twenty-four years, and runs freely through them. In other cases, on long spans, and especially where wires pass freely over soft porcelain, the wear has been extremely great. Even so heavy a wire as 240 mils has chafed on spans over 100 yards. 125 mils so frequently breaks that it has been necessary to protect it at the supports by wrapping it with binding wire.

On very long spans it is necessary to shackle off each length so as to transfer the centre of motion to the bolt of the insulator, and allow the wire to swing freely. The "lugs" or projections of iron caps sometimes injure the wire by notching it, as well as by friction. Iron hooks are very objectionable. The wire should always be very tightly bound to the insulator so as to reduce the friction to a minimum; and it must be recollected that as soon as the zinc is worn off, galvanic action may be set up so as to corrode the iron.

When the position of the poles is altered, as when a line is

reset, the wire must be carefully examined, the worn places cut out, or, if the wear is slight, wrapped with binding wire.

270. On the older lines the wires were allowed to pass freely through the insulators, and were strained by a drum and ratchet at each half-mile. This method has been abandoned in favour of binding to every pole, because under the old method a broken wire runs down half a mile in every case, but on a properly bound line seldom more than 100 or 200 yards, and because the older form of insulator is necessarily bad, leakage occurring in two directions instead of one.

65 mils charcoal wire is the best for binding: when the line-wire is thick—240 mils for instance—and requires to be very firmly fixed, the binding should be doubled, for a thicker binding-wire cannot be applied so effectively.

In binding, the turns of wire should be made always in the same direction, or they will not be firm; the main wire is twisted somewhat in the process, and when it recovers its normal position it will slacken one side of the binding if the turns are in opposite directions.

The binding stretches, and requires occasional renewal. The old pieces must not be allowed to remain on the main wire, for if they become loose they will cut it by being spun round and round by the wind. They cause a peculiar rattling noise, and can be detected by it.

271. The distance through which a broken wire will run down depends very much upon the way in which it is bound, as is well shown by the following experiment:—

(1.) On a line of 24 poles to the mile, a wire of 240 mils was bound with a single wire of 65 mils at each insulator, and securely soldered, so that it could not slip, and was then filed through in the centre of its length. It tore itself from the fastenings throughout the entire distance.

(2.) Next it was bound as before, but soldered at every *fourth* pole; it then broke away from 20 poles only. Here the unsoldered bindings allowed it to slip a little, and thus eased the strain.

(3.) Thirdly, it was bound doubly strong, but not soldered; the first binding stretched a little, and all the arms were strained,

but it did not tear itself away from a single pole. The wire, therefore, should be so bound as to slip a very little at each support, and thus prevent the sudden jerk.

272. The top of a pole is the best position for an important circuit. The saddle which holds the insulator must be fixed with screws, as nails split the wood when driven at the end of a pole, and will not bear a strain. If the pole is creosoted, screws are also needed for brackets when the strain is great, as nails will draw out of the wood.

273. When boucherised (coppered) timber is used, all nails, screws, and bolts must be galvanized. It is better also to dip them in tar before fixing them. The threads of all bolts should be greased.

274. The same *circuit* should always, as far as possible, occupy the same place on the poles, so that it may be readily identified. Wires are generally known by numbers: that on the top of the pole is called *number nought*; the upper one on the side next the road or railway, *number one*; the corresponding wire on the back of the pole, *number two*; and so on. On a railway, when the wires cross the line, it is very convenient to arrange them so that the same order is continued, *number one being always the top wire next the rails or road*. But this cannot always be done, and number one is sometimes the wire to the right hand when one faces the *up*, or principal station.

275. When it is impossible to carry the wire free from the branches or leaves of trees, it is sometimes covered with tarred tape or percha tubing, as a partial insulator, to prevent in some degree loss of current.

276. Short pieces of wire must never be left lying about, but should be collected, or placed where they cannot be found by passers-by, as persons very frequently cause interruptions to signalling by throwing them upon the line-wires.

277. Thick wires should never be used in crossing a line of railway. If a stay give way, or anything occur to lower a wire, it will be caught by the train, and, being too strong to be readily broken, will allow the engine to drag down a considerable length of the telegraph. If a thin wire be used, the engine will snap it, and no great harm will ensue.

278. Stranded wire has been extensively used for long spans ; but it rusts much more rapidly than solid wire, owing to its larger surface, and gives way very rapidly where exposed to smoke : steel, or the so-called *homogeneous iron*, is to be preferred when the span is too long for ordinary wire.

279. The weight of a suspended wire causes it to hang in a curve, or to dip. The more it is tightened the less it dips, so that its *tension* or strain is proportional to its dip. The weight of the wire in the span, or the dead weight on the poles, depends on its size and length. For a line of 20 poles to the mile, where the spans are 88 yards, the ordinary dip is about 18 inches in mild weather, which gives, for 170 mils wire a *tension or force tending to break the wire*, of 420 lb., the breaking strain of the wire being 1,300 lb.

The tensions of two wires of different gauge, the span and dip being the same for each, vary as the squares of their diameters. Thus, if the tension of a span of 125 mils wire be, say 90 lb., the tension of a similar span of 170 mils will be 160 lb., because the diameters of the wires are as 3 to 4, the squares of which numbers are 9 and 16.

280. If it be required to increase the difference between the supports, or to increase the *span*, and yet to preserve the same *tension* in the wire, the dip must be increased as the square of the number of times the distance or span is increased. Thus, if for a span of 100 yards the dip be 1 foot, for double the distance, 200 yards, the dip will be $2 \times 2 = 4$ feet ; for three times the distance, $3 \times 3 = 9$ feet, and so on.

The mathematical formula is :—

$$S^2 : s^2 :: D : d,$$

where S is the original span, s the proposed span, D the original dip, and d the dip required by the increased span to preserve the same strain or tension.

$$\text{Thus } 100^2 : 200^2 :: 1 : 4,$$

$$\text{and } 100^2 : 300^2 :: 1 : 9.$$

From this formula, which is sufficiently correct for all practical purposes, may be ascertained, not only the dip of any proposed span, but the span of any proposed dip.

Thus, suppose we have 30-foot poles, and wish to learn the greatest distance at which they can be placed apart so as to keep the wires 10 feet from the ground, and to preserve the strain equal to that given by a dip of one foot in 100 yards, we have—

$$100^2 : s^2 :: 1 : 20,$$

because we have sufficient height to allow a dip of 20 feet. Multiplying together the two extreme terms of our proportion and the two means—

$$\begin{aligned} 100^2 \times 20 &= s^2 \times 1 \\ \text{and } s &= \sqrt{200,000} = 447 \text{ yards nearly.} \end{aligned}$$

281. The *span* being the same, the *dip* will vary inversely as the *tension*. If with a strain of 200 lb. it dips 30 inches, with a strain of 300 lb. it will dip 20 inches, and with 400 lb. 15 inches.

282. The tension is not the same at all points of the curve. It decreases from the supports downwards, and is least at the lowest point; but in lengths under 150 yards the difference is small.

When both supports are the same height, the lower part of the curve is in the centre of the span; when one is higher than the other, the lowest part is nearer the lower support, so that the greater part of the weight of the wire is borne by the higher pole. In calculating the strain, the wire should be considered as if prolonged beyond the lower support to a point equal in height to the upper one; and the strain will be proportional to the length thus increased, or to twice the distance from the top to the bottom of the dip. It is desirable, therefore, that the two ends of a long span should be fixed as nearly as possible at equal heights.

283. When the tension at the lowest point of the curve is known, that at any other point may be ascertained by adding the weight of a piece of the same wire, whose length is equal to the difference in level of the two points. Thus, the greater the tension and the smaller the dip, the less will be the difference of tension at different points.

If it were possible to pull the wire up perfectly straight, the tension would be equal in all parts.

284. As the tension is least at the lowest point of the curve, a wire is more likely to break at or near its supports, than in the centre of the span ; and the centre of a very long span may with advantage be made of lighter wire than the ends ; for then the ends will not have so much weight to support, while the centre will be strong enough to resist the tension at the lowest point.

285. The weight of a wire increases with its strength (the quality being the same) ; the advantage, then, in using thin wire for large spans is, that the supports have less weight to carry.

286. The greater the dip, the greater the *weight* of wire to be supported, so that there is a point beyond which the dip cannot be increased with advantage ; because the tension arising from the *weight* will increase more rapidly than that due to *tightness* will diminish.

For a distance of 1,000 yards, with a wire of 170 mils, the supports being on the same level, the strains will be nearly as follows, as given by Blavier :—

Dip.	Proportional strain at lowest part.		Proportional strain at supports.
186 yards	70	..	88
218 "	60	..	81
271 "	50	..	77
353 "	40	..	75
516 "	30	..	81

So that, with a span of 1,000 yards, and a dip of 353 yards, the strain at the supports will be the least possible, while with a dip of 516 yards it will be as great as with a dip of only 218 yards.

But in practice the dip cannot be made as large as those in the table, so that the practical rule for long spans is, make the supports as nearly equal in height as possible, and the dip as large as you can.

287. As metals expand and contract with the variations of temperature, wires put up in the summer must be strained less tightly than if fixed in winter, or their contraction in frost will

break them ; and if put up too slack in winter, they will be liable to get in contact in summer.

Although the strength of a wire increases in proportion to its size, yet a thick wire will be as liable as a thin one to be broken by frost ; for a thick wire will obviously exert more force in contracting than a thin one, and will be more likely to tear down its supports if strained too tight.

Whatever the gauge of the wire, it will always take the same sag for the same span ; and, therefore, if upon one line of poles one wire has been properly strained with the recognized tension, every additional wire which may be added will be properly strained if it is properly regulated.

288. A wire should never remain tightened up to more than one-third of its breaking strain. There is a great tendency to err in straining too tightly ; it must be borne in mind that, however carefully wire may be manufactured, flaws cannot be entirely prevented, nor can they be thoroughly removed by *killing*.

The shorter the span, the greater comparatively is the effect of contraction by cold, and more wires are broken by frost in short than in long spans, when the tension of the wire is the same in each.

289. Iron expands $\frac{1}{1118}$ of its length ; or about $4\frac{1}{16}$ inches per mile for every ten degrees of heat ; so that between winter and summer, or 32° and 62°, there will be on a line of 20 poles to the mile a difference of length in each span of wire of nearly seven-tenths of an inch.

When there are twenty poles to the mile, and 170 mils wire is used, a dip of 14 inches is equivalent to a strain of about 540 lb. or nearly half the breaking strain. Now, by experiment it has been ascertained that between 54° F. and 25° F. the difference in dip is three inches ; so that if a wire is pulled up in mild weather to a dip of 14 inches, it will take at 25° a strain of about 700 lb. the equivalent of a dip of 11 inches, and if at all faulty it will break.

290. JOINTS.—There is nothing more important than the perfect continuity of a circuit, and this can only be attained when every connection or joint is well *soldered*.

No joint is secure as regards conducting power, unless it is *soldered*, however tightly the wires may be twisted together. It is not even sufficient to clean the ends and cast an ingot of metal over them, as has sometimes been done. The same remark applies to every connection exposed to damp, whether a binding screw, or a pair of tinned copper plates tightly screwed together, as in a line-testing box or at a tunnel-end. Electrolysis, and therefore corrosion, invariably occurs if moisture be present, and the joint ceases to conduct.

A very useful pocket soldering stove has been lately patented. It is a copper box, about 4 inches long and 2 deep, with holes for the admission of air, having a hollow on the upper side large enough to contain sufficient solder for a joint. The box is fitted with a wood handle. The fuel is charcoal, prepared so as to light readily and burn steadily.

291. A twisted joint is apt to break from the hardening of the wire in twisting. The so-called "Britannia" joint is the strongest and best (Fig. 59).



FIG. 59.

It is made by slightly bending up the ends of the two wires, laying them side by side, binding them tightly together with wire of 65 mils, and well soldering the whole. The bent ends should be *cut off close*, to prevent the formation of wind-contacts; for when wires are blown together they are frequently hooked permanently by such projections. Joints, even when well made are open to the same objection.

In "terminating" a wire it should never be twisted, or it will break. It must be wrapped once round the insulator, and bound



FIG. 60

as shown in the illustration (Fig. 60). The binding-wire need not be soldered.

292. Chloride of zinc (or "spirits of salts killed with zinc"), with a little free muriatic acid added to clean the wire, is the best solution for soldering. The rain quickly clears away the excess of chloride; but when copper and iron wires are connected, it is better to wash off the chloride of zinc, and to smear the joint with paint or rosin, or even to solder with rosin only, especially in a smoky place, to prevent local action between the metals.

Joints in hard wire must be soldered at as low a heat as possible, so as not to soften the iron, or it will stretch and break where softened, if the strain is considerable.

293. The noise caused when the wires are set in vibration by the wind is sometimes very annoying, particularly when a pole or standard is fastened to a wooden house. To prevent it, the insulators are sometimes wrapped with vulcanized rubber, or the wire itself is first enclosed in a vulcanized tube, and then wrapped with lead wire about a pound in weight. Strips of wood about $18 \times 1\frac{1}{2} \times 1$ inches, grooved slightly to fit the wire, may be placed on each side and screwed together so as to hold it *firmly*. The object in each case is to prevent the vibration, and the proper distance of the *damper* from the support must be found by trial. A short chain, placed between the wire and insulators, is said to have the same effect. Strand wire is far less noisy than solid.

294. INSULATORS.—The surface in contact with the wire should be as small as possible, so as to diminish the leakage. The wire sometimes lies on a knife-edge without being bound to the insulator: this secures the greatest possible insulation, other things being equal. But when a wire passes freely over the insulator, the constant vibration causes it to cut the porcelain or be worn away itself, especially in sandy districts. It should therefore be *bound very securely* to its supports, for loose binding does not stop the wearing action. (269.)

For fixing bolts into insulators, *plaster of Paris* mixed with a little liquid glue to prevent its setting too quickly, or *black cement*, composed of 1 part of rosin, 2 of sand, and 1 of smiths' ashes, is used.

Sulphur, in other respects the best of all cements, splits the insulators, apparently by expansion. It was expected that the splitting would be prevented, if the iron were perfectly protected from the sulphur, as when the bolts are covered with ebonite; but it is not so. Oxide of iron mixed with the sulphur is said to render it safe, but it is not necessary to employ sulphur at all.

295. Where the porcelain is exposed to injury from stone-throwing, the insulator is covered with an iron cap, but this covering should be employed as sparingly as possible, as it prevents the rain washing the outer surface. Caps cast with openings to admit rain have recently been introduced, and will probably be found better than if solid.

296. For terminating wires, the insulators should be so fixed that they will take a direct strain. Shackles are to be preferred to insulators fixed upon a pin, for as the iron pin passes through the insulator of the shackle, should the earthenware break, the

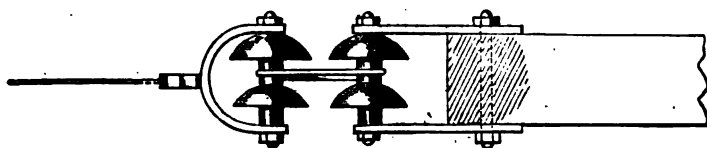


FIG. 61.

wire will not fall; but on the other hand, as the current can escape upwards as well as downwards, it requires two insulators, or a double shackle, as in the figure, to give the same resistance to leakage as that of an *invert* of the same model and size.

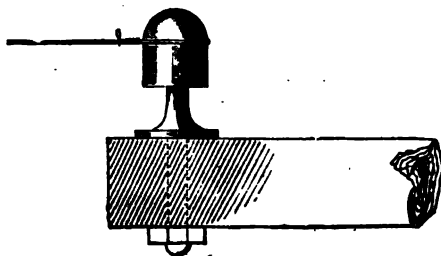


FIG. 62.

Insulators should always be securely screwed to the arms or brackets, for when the pins or stalks simply drop into holes they are frequently lifted out by the wind, causing a stoppage.

297. **LEADING WIRES INTO STATIONS.**—As percha wire is very perishable when exposed to air and light, it is imperative to leave as little as possible uncovered, and to enclose it in an iron pipe or a well-made wood casing, carefully fitted and painted. The wire should not pass near a lead gas-pipe, lest a lightning discharge should take place between them.

The percha should be covered with tape, and varnished with Stockholm tar, in outdoor work. The length left exposed to the air must have a double coating of tape and tar. Paint injures percha.

As the dirt on the exterior of percha conducts when damp, a short length of the loop which extends from the casing to the line-wire may be protected from rain by a porcelain or stoneware bell or large tube, so that a portion of dry surface may break the line of leakage.

However well covered with tar exposed percha may be, it needs frequent re-tarring, or it will decay in time.

298. **IN FIXING EARTH-PLATES** care must be taken that the principles laid down in section 98 be complied with, so that a perfect earth may be obtained.

Occasionally an earth cannot be found; a return-wire is then necessary. It is generally better to use a return-wire for circuits of less than half a mile, unless a water-pipe is available. It of course need not be insulated.

299. **OVER-HOUSE WIRES.**—When wires are carried over houses, it is better to use a light strand, because it is not so liable as a solid wire to be set into noisy vibration by the wind. It may, in smoky towns, be protected with a wrapping. Over-house wires are erected in long spans, and are shackled off at every support, so that they may not be worn by friction at the insulators, and that each span may be independent as to stability. The poles are iron; they are light, and are slipped into a cast-iron saddle, which fits upon the ridge of the roof. They are well stayed in every direction, the pole merely carrying the weight of the wires, its stability being secured by the stays.

Sometimes a number of insulated wires are made into a cable, which is suspended by hooks from a pair of wires of the usual kind, carried in the manner described above. These cables must necessarily be light, and their insulation is consequently defective; it is, however, capable of considerable improvement.

The great defect of over-house wires is in their insulation. Shackles do not in any case insulate well, and they soon become coated with smoke, while from their position they cannot be frequently cleaned. The author cannot recommend their employment as portions of long circuits, though their insulation is sufficient for local telegraphs.

300. UNDERGROUND WIRES.—Underground wires are either drawn into pipes, or laid in troughs fitted with a moveable cover. It is very much more easy to place the wires in a trough than to draw them into a pipe, and there is less chance of injuring them; but it is much more difficult to execute repairs in a trough, and practically it does not appear that the process of drawing into a pipe injures the wire if ordinary care be used.

When pipes are employed, the entire length may be replaced by new wire, without interrupting the communication for an instant, or even opening the ground except at the drawing-in boxes; while if a trough is used it must be opened throughout, unless it has been constructed so as to allow the cable to be drawn out, in which case it would be much more expensive than pipes. The plan which has been pursued for many years in London and the larger towns is to lay down a pipe under the flag-stones, amply large enough for all the wires likely to be required. Oblong "drawing-in" boxes, 30 inches by 11 inches, and 12 inches deep, with lids formed of an iron frame, into which a piece of flag-stone is fixed, are placed at every 100 yards if the line be straight, and nearer if it be curved. The pipes should be well cleaned, and tarred inside while hot, to prevent rust, for rust causes the wires to adhere so strongly to the iron that it is difficult to detach it.

301. The wires are sometimes made into cables, 400 yards in length, with a very slight twist, and covered with braided hemp, like the handle of a whip, but it is more usual to spin tape

around each separate wire, and simply to tie them together as a bundle, cutting the ties off before they enter the pipes. In either case the percha, tape, and hemp are well covered with Stockholm tar. Stockholm tar preserves percha more completely than any other substance, but gas-tar is injurious.

302. When a length is found to require renewal, a new "*cable*" is connected in a loop between it and the next length, and as the defective piece is drawn out the new piece is drawn in. The defective wires in the old *cable* are repaired at the factory. Thus the whole of the *street-work* can be replaced by new wires without interrupting the communication. Extra or *spare* wires are always provided when a new length is drawn in, so that it may not require renewal until several wires have failed.

It is impracticable to draw out a portion of the wires, because the friction of one wire upon another would cut through the coating. Nor can additional wires be drawn in without great risk, unless both old and new have been made into a cable and covered with hemp or canvas. But the objection to covering a cable thus is, that should it rot partially or be injured, the defective portion will strip off and choke the pipe. When the wires are taped *singly*, the choking is prevented.

It is always desirable to make all the joints at the same part of the cable, so that they may be easily found, because although joints made in the factory should be as sound as any other portion of the sheathing, they cannot either be so well made or so carefully tested in the open air. At each set of joints the wires are labelled.

Faulty wire should not be used for permanent work, although its insulation may be good enough at the time for the circuits on which it is to be used, because a fault always increases, and will in time become serious.

303. TUNNELS.—Percha wire, well taped, tarred and sanded, is laid in a wood trough fixed to the wall. A cover is placed over it, coated with zinc, to prevent accidents from the cinders thrown out by the engines. In fixing the cover great care is necessary to prevent piercing the wires, and it is better not to nail it on, but to *tie* it.

Sometimes an iron pipe is used instead of the trough, or a cable covered with canvas is fixed to the wall.

304. Percha wires have occasionally been laid in a pipe filled with Stockholm tar, which it is expected will preserve the percha for a long time.

The pipe is fixed as level as possible, and T pieces, closed by screwed covers, are introduced at each 100 yards.

The wires are drawn in, all at the same operation, through a mixture of boiled tar and linseed oil, slightly warmed to make it more fluid. They will carry a portion of tar with them, and the pipe may be afterwards filled by screwing on vertical pieces at each end, into which the tar may be poured. The pressure of the head of tar will carry the air out before it, which will escape at the L pieces which are left open. Each opening should be closed as the tar reaches it. If the tunnel is too long for the pipe to be filled from the ends, vertical pipes for pouring in can be fixed at the L pieces. The objection too is, that the tar will harden in time, so that the wire cannot be drawn out again without injury.

305. Wire is sometimes insulated by being embedded in asphalte.

The best results have been obtained in this way. A wood trough, strong enough not to warp or bend, is fixed to a wall. The bottom of the trough is covered with a layer of hot bitumen, softened with Stockholm tar, but it must be made of such a consistence as not to crack in the coldest weather, nor to become so soft in summer as to permit the wires laid in it to sink into contact one with another, a matter of very great difficulty.

After the bitumen has cooled, the first layer of wires is placed upon it, the wires being kept from touching one another by moveable combs while they are covered with the mixture. This must be sufficiently warm to adhere perfectly to the first layer, yet not so hot as to melt it. More wires are then laid, and the operation is repeated until the trough is full. Bare iron or copper wire can be used, or defective percha wire.

As moisture prevents the blending or adhesion of the several layers of bitumen, the operation cannot be carried on in damp weather. If a drop of rain fall into the trough, it will be con-

verted into steam by the hot mixture, and will cause a hole, perhaps not large enough to be observed, but sufficient to let in water and create a fault.

Mineral bitumen succeeds better than that made from gas-tar, and Stockholm tar is to be preferred to gas-tar, for the latter causes the mixture to become brittle after a time.

A serious objection to the system is the difficulty of repairing it should it become faulty, and it is not economical in first-cost.

Old gutta-percha wire, too much decayed for ordinary purposes, may be utilized in other ways. It may either be made into a cable or bundle of wires, covered with canvas, and injected with a very soft mixture of Stockholm tar and asphalt by the vacuum process; or, after having been well rubbed with a somewhat harder tarry mixture to fill up the cracks and other defects, it may be laid in a trough filled with the same material. These methods give a very fair insulation, except in places where it is constantly wet.

306. JOINTING COVERED WIRE.—Unless a professional jointer who can be held responsible for his work is employed, no one but the line-man in charge of the work, who will have the trouble of repairing it if defective, should be entrusted with the delicate operation of making joints.

Cleanliness is most essential to success. The fingers should be used as little as possible, and must be kept very clean.

Prior to making the joint, the gutta-percha is removed from the ends of the wires for about $1\frac{1}{2}$ inches, and the copper wires are carefully cleaned by scraping; the wires are twisted together for 1 inch, the sharp ends being closely trimmed off. The joint is then soldered with *rosin* and good soft solder containing a sufficiency of tin.

After this the gutta-percha is scraped, or very carefully pared back for 2 inches, to remove its outer surface, which is oxidized, and will not join properly; the wire joint is covered with Chatterton's compound, and the gutta-percha heated on both sides and tapered down over the joint until that from each side meets. The junction is completed by means of a warm jointing tool, care being taken to mix the gutta-percha well without burning.

As soon as this has cooled, another coating of Chatterton's compound is spread over the gutta-percha, taking care not to burn the compound.

A new and clean sheet of gutta-percha is then heated by means of a spirit-lamp, and while so heated carefully stretched so as slightly to thin it. Then, while it and the Chatterton-coated joint are still hot, it is laid on the joint, and pinched tightly round it with the finger and thumb, after which it is trimmed off close with scissors. The seam is again pinched, and carefully finished off with a warm tool, so as to mix the gutta-percha of the two sides, and the coating of the wire itself, well together.

The joint, when cool, is again covered with Chatterton's compound, and a longer and larger sheet of gutta-percha is laid over it, pinched, cut, and tooled off as before.

When the joint is complete, another coating of Chatterton's compound is applied over the whole, well tooled over the joint, and, when cool, rubbed with the hand, well moistened, till the surface is smooth.

The mixing of the old and the new gutta-percha is most important, and joints generally fail from this having been imperfectly done, or from the percha being overheated.

307. *Second Method.* (Sabine's "Electric Telegraph.")

Cut the ends of the core flush. Warm the percha on each wire with a spirit lamp for three inches, and, when soft uniformly all round, push it back so as to form a knob. Cut off the exposed wire, leaving sufficient to form a joint. After soldering it with rosin, wash the wire with naphtha, warm it, and coat it with compound.

Warm one of the knobs, and draw it again over the wire up to the other knob; trim it, knead it well into the second knob, and coat with compound. Then draw the second knob over the first, coat with compound, and cover with sheet percha as in the former method.

A very excellent temporary joint may be made by drawing a piece of vulcanized rubber tube over the ends of the percha after having soldered the wire, and wrapping it tightly with wire.

Chatterton's compound is one part, by weight, of Stockholm tar, one of rosin, and three of percha.

PART VIII.

ORDINARY TESTING.

308. It is desirable that all important circuits be tested daily for insulation and resistance, and that the test be so recorded as to be capable of being reduced into units of resistance. These tests will point out leakages and faulty connections, so as, in very many cases, to enable their removal to be effected before they interfere with the working of the circuit, and will give the data necessary for determining the distance of faults.

309. The line-wires at all important stations are connected to *terminal* screws in a *test-box*, which contains also similar binding screws joined to wires leading to the instruments and to the earth.

In the daily testing, the distant station disconnects the line wires at a fixed time for a certain number of minutes. The *insulation* test is then taken by connecting the battery, galvanometer, and line, as shown in the diagram.

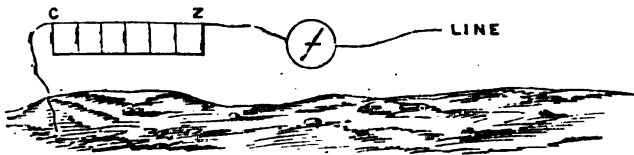


FIG. 63.

The distant station next puts the line-wires to *earth* for a second fixed period, by screwing a bright copper wire to the *earth terminal*, and to all the line-wires, which are still left disconnected from their respective instruments. The *continuity* or

resistance test is then taken. The connections at the testing station are as in the diagram, but the distant ends of the wire, instead of being free, are connected to the earth.

310. Blavier, in his Manual, describes the French method thus, A and B being the two stations :—

A sends a current through his "detector" during two minutes.

For the first minute B leaves the wire disconnected, and during the second minute puts it to earth through his own detector.

Each station registers the results.

During the next two minutes B sends the current, and A makes the changes previously made by B, each registering as before.

The tests made when the wires are *disconnected* show the leakage or insulation resistance; those made when the wires are *to earth* give the resistance of the wire and apparatus in circuit.

The tests taken at the opposite ends never agree, the resistance of the wire making a distant fault appear smaller than one near at hand, not to mention other obvious causes of disagreement, such as dissimilar battery-power; but it is useful, because it shows the working current received from the distant station.

311. The worse the insulation or the greater the conducting power of the wire itself the larger the deflection of the needle, because the resistance is decreased. If then it were possible that every test throughout the world could be made with batteries of equal power and galvanometers uniform in sensibility, tests made in different places or at different times might be compared. But the same battery and even the same galvanometer vary in power and sensitiveness from time to time, and in consequence give variable results, it is therefore obvious that by no other method than the reduction of each test to a common standard of resistance, can the observations, taken at different times and in different places, be compared.

Each principal office should therefore be provided with the means of reducing the daily tests into *units of resistance*. In order to compare the insulation of one circuit with that of

another, it is necessary to calculate its resistance *per mile*, by multiplying the result of the tests by the length of each circuit in miles, for were this not done, the longest wire would appear to be the most faulty. The comparison even then is not absolutely correct, but it is the nearest approximation which can be obtained.

312. When better apparatus is not to be had, the ordinary vertical "*detector*" may be used, but it is not susceptible of accuracy. Its scale is not correct above 20° , and the friction of its pivots interferes with the readings below 40. The most trustworthy part of the scale lies between 40° and 60° .

Even where only the very roughest tests are required, the battery-power must be so regulated as not to deflect the needle of the galvanometer to the full extent of the scale, for two wires may differ very much in resistance, and yet appear to test alike if both give what is called *full deflection*, such a number of cells should therefore be used as will cause the deflection to range between 40° and 60° .

The ordinary detector can only be used for measuring insulation resistances with anything approaching accuracy when we read the deflection, and reproduce it through resistance coils by varying the battery-power. If the office possesses a coil, the resistance of which is known to be, say 500 ohms, it can be used as a standard. Suppose that with one cell we obtain a reading of 50° through the coil, and that 20 cells are required to obtain the same reading through the wire we are testing. Then as $1 : 500 :: 20 : 10,000$, the resistance of our wire will be 10,000 ohms.¹

But it is seldom that a series of cells are exactly equal in power, and the single cell may in some cases be even doubly as powerful as any one of the others. Moreover, it is only where the resistance of the battery and detector compared with that of the line to be tested, is so small, that it may be neglected, that the deflection of a galvanometer increases in proportion to the number of cells used.

The resistance of a wire may be ascertained by reading off

¹ Because if one cell gave a current whose strength was 50 on the coil of 500 ohms' resistance, 20 cells would have given 20 times as much.

the deflection obtained through the wire to be tested, and by subsequently placing the same battery and galvanometer in circuit with a set of resistance coils, altering their resistance till the deflection is reproduced. This system is accurate if a good galvanometer is employed.

313. Accuracy sufficient for ordinary purposes may be attained by the use of a *tangent* galvanometer, having its scale divided as shown in paragraph 129a; with a delicately balanced needle, and a standard coil of 1,000 ohms' resistance.

As the graduation of this galvanometer is correct throughout, and the friction of the pivot the same at all angles of deflection, a much greater extent of scale is available than in any other instrument. If the coil is wound with two equal wires, so as to divide it into equal portions or halves, one half may be used for strong currents, or for resistance tests, and the entire coil for weak currents, or insulation tests; the readings obtained with the half-coil must be multiplied by two. Or a shunt may be attached to it, which is a wire connecting the two ends of the galvanometer coil, so as to divert a portion of the current, and reduce the sensibility of the instrument.

First test the strength of the batteries, by ascertaining what deflection is obtained upon the *standard resistance R*, as in the following diagram. This is called *taking the constant* of the instrument.

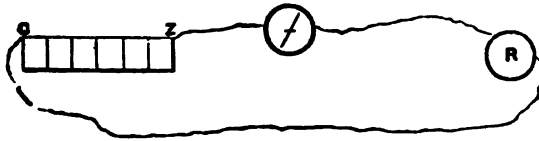


FIG. 64.

Then test for insulation and resistance in the manner already described.

When a tangent or other horizontal galvanometer is used, great care is necessary to avoid the disturbing action of masses of iron, the electro-magnets of the instruments, and of the currents through the wires which pass under the desks. If a more suitable situation cannot be found for the instrument, it may be placed in an iron box without a lid.

314. The daily tests taken by this method by a tangent galvanometer, having a scale of tangents (129*a*), may conveniently be recorded in the following form:—

Date.	Constant or Reading through 1,000 ohms.	READINGS THROUGH WIRES.				State of the Weather.
		No. 1.		No. 2.		
		Insulation.	Resistance. × 2.	Insulation.	Resistance. × 2.	
Feb. 19	60	12	75	16	50	Rain.

These readings can be reduced to units by proportion, thus:—

Deflection through the wire : Deflection through standard coil :: R of coil : R of wire.
Or $12^{\circ} : 60^{\circ} :: 1,000 \text{ ohms} : 5,000 \text{ ohms}$, the insulation of No. 1 wire,
And $75^{\circ} : 60^{\circ} :: 1,000 \text{ ohms} : 800 \text{ ohms}$, its resistance.

The greater the resistance, the smaller will be the deflection ; that is to say, if 1,000 ohms give a deflection of 60° , a deflection of 12 will represent five times the resistance, or 5,000 ohms. Or, more simply, because the standard is 1,000, add three ciphers to the reading obtained upon the standard, and divide it by the reading obtained upon the wire, thus:—

$$\frac{60,000}{12} = 5,000. \qquad \frac{60,000}{75} = 800.$$

It is not necessary to reduce the readings each day to ohms, but only to record them in such a manner that they can be reduced when it may be desired.

315. A set of resistance coils, as has already been explained (78), is a number of bobbins, filled with fine wire, each equal to a certain multiple of the unit of resistance, the *ohm*. By their use, electrical measurements taken after long intervals, or in different parts of the world, can be compared in the same way as if they had been weights or distances, because a definite and well-known standard is used. Copies of the

standard of resistance are as easily made as those of the pound or yard.

The wire of the coils must be of a metal or alloy which does not vary much in resistance with temperature. A reference to Table XI. will show how greatly the several metals differ in this respect. Copper will be seen to be very unsuitable, inasmuch as its variation is $\cdot388$ per cent. for each degree, while German-silver is $\cdot044$, and an alloy of platinum and silver $\cdot031$, or only about one-tenth of copper. Thus, an error in a test due to the absence of a correction for temperature, would be ten times larger if copper coils were used than with platinum-silver coils.

Moreover, as the resistance of these alloys is very much greater than that of copper, 13 times for German-silver, and 15 times for platinum-silver, a much less quantity of wire is required to form a coil.

316. To avoid the effect of extra currents (173) when making and breaking circuit, and to prevent the coils affecting galvanometers near them, the wire is first doubled, and then wound on the bobbin, one half then neutralizes the other half, because they are wound in contrary directions.

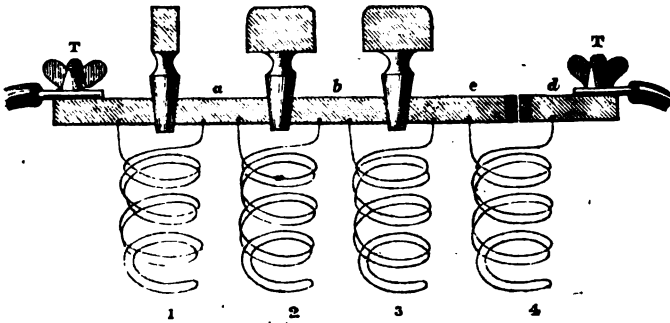


FIG. 65.

317. The several coils are arranged in a box as in the figure. The connecting pieces *a b c d* are made of brass, mounted generally on an ebonite slab covering the top of the box. The bobbins are slipped upon pins fitted into the top, so that any

one of them can be removed for adjustment without disturbing the rest. Brass plugs with ebonite handles are fitted in holes between the connecting pieces to short-circuit the coils. When any one of these plugs is taken out, the coil is thrown into circuit. Thus, if the four coils shown in the figure have 1, 2, 3, and 4 ohms resistance respectively, and the plug between *c* and *d* is removed, 4 ohms resistance is thrown into the circuit with which the coil-box may be connected by the wires, T, T'.

Thick wire should be used for the small resistances, because, as a slight difference in length will not materially alter the resistance, it is easier to obtain accuracy in adjustment than if a finer wire were used.

The box of coils is sometimes made circular, contact being made by moveable levers, arranged to move like the hands of a watch.

318. The most accurate methods of testing are by means of the *differential galvanometer*, or the *Wheatstone's balance*, and a set of resistance coils and it is desirable, occasionally, to employ one of these more accurate methods.

319. The construction of the differential galvanometer is described in paragraph 127. In testing a line wire by the "differential" for insulation, the connections are made thus:—

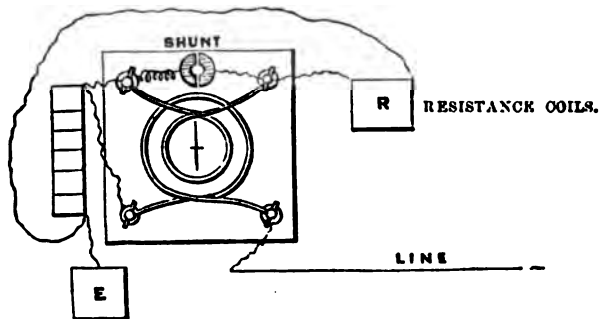


FIG. 66.

In testing for resistance or continuity, the line can be connected to earth at the distant end, or, what is better, looped

with another wire whose resistance is known, or which is exactly similar, thus :—

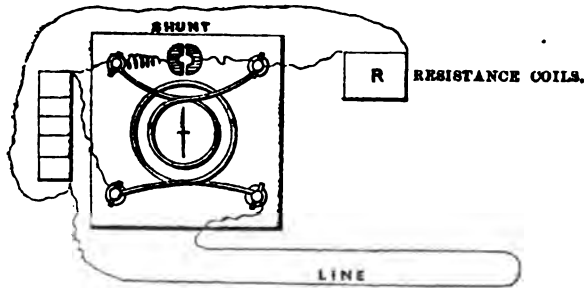


FIG. 67.

When a shunt is used, the reading of the resistance coils must be multiplied by the *value of the shunt*—10, 100, or 1,000, as the case may be.

320. The *Wheatstone Balance* or *Bridge* is more generally employed than the differential. Any good galvanometer may be used with it; the galvanometer need not even be graduated; all that is necessary is, that it shall be sufficiently delicate to indicate the presence of a very feeble current.

The balance in its original form consists of three sets of resistance coils, arranged so as to form three sides of a parallelogram, the wire to be tested being the fourth side. In practice the apparatus does not bear this form, for it is arranged so that the coils may occupy as small a space as possible. Yet it is convenient in describing the balance to use the parallelogram, for the figure is readily borne in mind, and is a great assistance both in comprehending the principle involved and in arranging the connections for a test.

321. The principle is perhaps more readily understood if it be supposed that one pole of the battery is put to earth: let it, then, be imagined that this has been done, although it is not necessary to employ the earth in testing. When one pole of a battery is put to earth, and the other pole connected to a long wire so that a steady current flows through the wire to earth, the potential of the wire will fall regularly at equal intervals of resistance from a maximum at the battery end, E , to zero at the

end *F* connected to earth, for the earth is always at the zero of potential; and if the perpendicular *H E* represents the potential

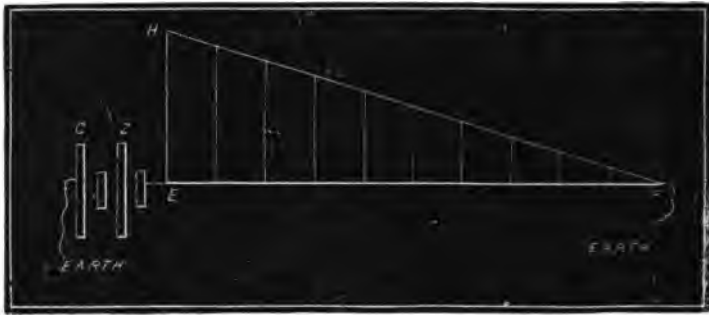


FIG. 68.

at *E*, the perpendiculars or ordinates at the succeeding points will represent the potential at those points, as may be proved by the electrometer and a set of resistance coils.

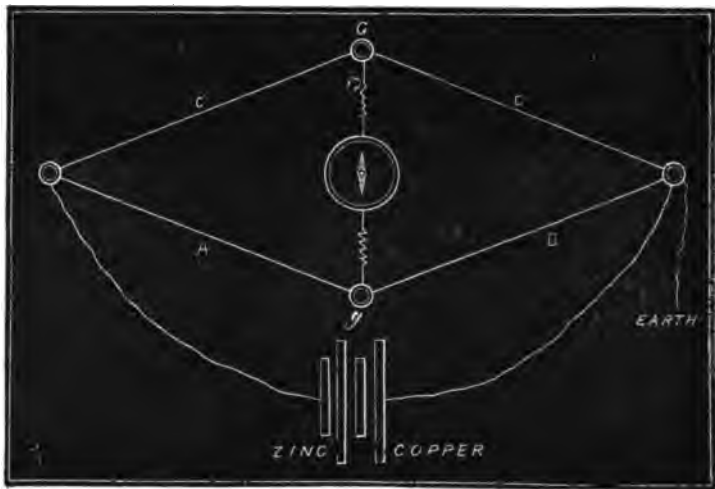


FIG. 69.

Let us then suppose one pole of the battery put to earth, say the copper or positive pole; that the wire *E F* is split into two

precisely equal wires, C D and A B ; that these wires are separated throughout except at their ends, and that they are bent into the form of a parallelogram. This particular form is not essential ; all that is necessary is that the two wires shall be separate except at their ends. Now the resistance of the two wires being perfectly equal and uniform, the fall of potential will proceed precisely as in the single wire, and will therefore be *equal* at any two points equally distant, *in resistance*, from the zinc end, as at A and C, G and g, or B and D. As a current is caused by a *difference* of potential, and cannot exist between points of the same potential, no current will pass through the galvanometer in the *bridge* connecting G and g, however powerful a battery may be used ; that is to say, there is no force tending to cause the current to pass over the bridge. Nor clearly would there be if the bridge were placed between A and C or between B and D.

But if it were placed from D to A, a current would pass, because D being further from the earth than A, is at a higher potential, and the galvanometer would be deflected.

322. To take an illustration from the flow of water. Suppose the two wires forming the parallelogram were two troughs conveying water from one vessel to another. Equal quantities would pass through each, but no current would flow through a cross connecting pipe placed between G and g, because it would be as easy for the water to pass through A as through C, and as the head of water would be equal at G and at g, there would be no force tending to make it flow from one trough to the other through the connecting pipe. But, on the contrary, the water is higher at D than at A ; if therefore the pipe be made to connect those points, the head of water at D (*the higher potential of D*) would cause a current to flow through the pipe to the point of lower potential, A.

323. Again, when A bears the same *proportion* to C that B does to D, or when $A : C :: B : D$, no current will pass between G and g. For, let the resistance of the arm A be made 10, that of B 1, of C 1,000, and of D 100, the total resistance of the branch A B will now be 11, and that of C D 1,100 ; but the tension in each branch will have fallen *in the same proportion*, or to the same *fraction*

of its maximum ($\frac{1}{10}$ ths) at the points G and g, and the tension at G will therefore be equal to the tension at g.

324. When it is merely required to measure resistances varying within very narrow limits, the arms A and C may consist of two equal wires wound side by side on a bobbin, the arm B of a set of resistance coils, and D of the resistance to be measured.

325. For the general work of a telegraph station the following arrangement will be found efficient:—

The arms A and C consist each of three coils of 10, 100, and 1,000 ohms respectively, and are used for arranging the *ratio* of the balance; the arm B is a set of 16 resistance coils—1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1000, 2000, 3000, 4000 ohms

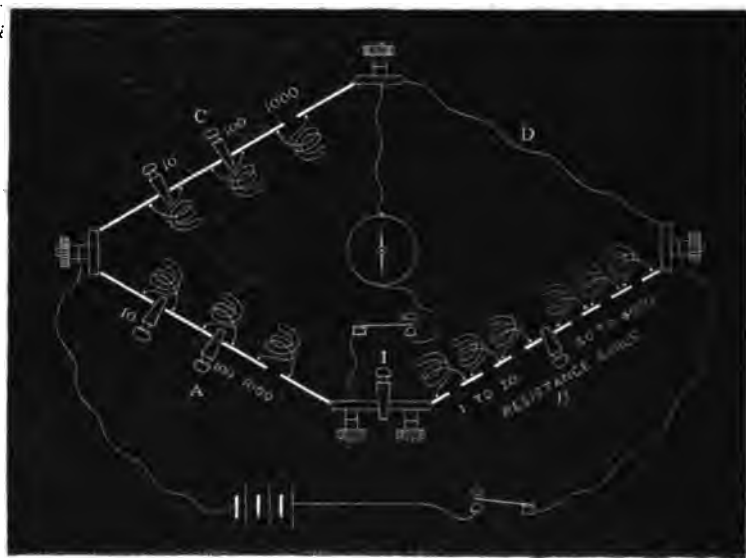


FIG. 70.

respectively, or 11,110 in all. A disconnecting plug, or *infinite* resistance, is placed between the 10 and 20 and at I. This set of coils serves as the measure. The wire to be measured forms part of the arm D.

326. To measure a resistance within the range of the coils

in B, A and C are made equal. When the resistance in B is greater than that of the line D the needle of the galvanometer will move in one direction, when less than that of the line it will move in the opposite direction, remaining unmoved only when the resistance in B is equal to that in D. For $A : C :: B : D$, therefore, as A and C in this case are equal, C and D must also be equal.

To measure a resistance greater than that of the coils in B, as in an insulation test, the resistance in the arm A is made *less* than that in C in order that A and C may bear such a proportion one to the other as will enable the coils in B to balance a resistance in D greater than their own, that is to say, greater than 11,110 ohms; thus, suppose the resistances in A and C are in the ratio of 10 to 1,000, and the resistance in the coils B is 10,000, then as $A : C :: B : D$, or $10 : 1,000 :: 10,000 : 1,000,000$. The resistance of the line tested would in this case be 1,000,000 ohms.

Conversely, when the resistance to be tested is less than that of the smallest of the coils in B, that is, less than one ohm, the resistance in the arm A is made greater than that in C; thus, if A equals 100 and C 10, the resistance in the coils B being 1, then as $A : C :: B : D$, or $100 : 10 :: 1 : 0.1$, the resistance of D will be one-tenth of an ohm.

It must not be supposed that no other ratios than 1 to 10 or 1 to 100 can be employed; the resistances in A and C may be varied at pleasure until they bear such a ratio the one to the other *as will enable the coils in B to balance the resistance in D*. This resistance is then found, as shown above, by the direct rule of three.

It is also necessary to adjust the *amount* of the resistance in A and C to the resistance to be measured.

The greater the resistance to be measured the greater should be the resistance in the arms A and C. In practice it will generally be found that for ordinary conductivity tests 1,000 in each of the arms A and C will be found to answer best; if a lower resistance were used, the galvanometer needle would move more sluggishly when testing a long length of wire, and the test would not be quite so accurate.

For insulation tests where the total resistance is less than 11,000 ohms, an equal ratio of 1,000 to 1,000 should be used. Where the insulation is above 11,000, a resistance of 100 in A and 1,000 in C will generally be required, except where the insulation is very high, when 10 in A and 1,000 in C will be necessary.

327. Except in special cases, the battery key is connected with the zinc pole of the battery, and the other key with one of the terminals of the galvanometer, so that either the battery or galvanometer circuits may be closed or broken at pleasure.

In all cases the key in connection with the battery should first be depressed, then the galvanometer key, making very short contacts by the latter, just sufficient to show to which side the needle is deflected, until the coils in B are nearly adjusted; or much time will be lost in making a series of tests, owing to the swing given to the needle, which will oscillate repeatedly before it again remains steady at zero.

When once the coils in B are properly adjusted and a balance obtained, it should be ascertained whether the needle will remain steady when contact is made and broken; but care must be taken to make the contacts coincide with the swing of the needle so as to assist it. A very feeble force frequently repeated will set a needle swinging, when the movement caused by a single contact is imperceptible.

328. In testing short lengths of wire, where the resistance in the coils is small, great care must be taken not to apply the battery current too long, otherwise the coils will become heated and their resistance will be increased. Care should also be taken that the plugs are kept clean so as to make good contact, but they should not be pressed in too tight or the ebonite tops will be liable to be damaged.

329. When a wire is tested for insulation, a portion of the current flows to earth over the insulators at each pole so that each succeeding insulator is tested by a gradually decreasing current; and the distant portion of the wire is tested by a current weakened by the leakage of the nearer portions.

This is always true theoretically, but not practically evident except in wet weather or on a badly insulated line, when the loss is great.

Again, if two wires of equal length and similarly insulated but of different gauge are tested, the thicker wire will have a resistance less than that of the other by the amount of difference in the conductivity of the two wires. The insulation test will be affected by this fact and also by the effect which the greater conductivity of the wire has on the leakage at each successive pole.

The results might be calculated by an extension of the formula given in paragraph 231 if it were possible to ascertain the resistance of each insulator, which cannot be done.

Practical illustrations can, however, be given.

When the resistance of the insulators is very high and uniform throughout the length tested, the leakages, as measured by the deflection of a galvanometer, will increase in proportion to the length of the wire, irrespective of its thickness or conducting power, because the resistance of the wire is exceedingly small compared with that of the insulators, and may be neglected.

When the insulation is so bad that the resistances of the supports bear a nearer proportion to that of the wire between them, a thick wire will test worse than a thin wire. Yet the thicker wire gives better signals, because the gain by its greater conducting power more than makes up for the loss by greater leakage. For the same reason *a circuit of many instruments tests better than a direct circuit in which there are none except at the terminal stations.*

Thus in an actual test, the insulation resistance of three wires on the same poles was very high, two megohms or two million ohms per mile. The wire A had a leakage equal to . . . 29

B	"	"	30
C	"	"	50

The sum of the three is 109

When looped so as to form one continuous wire, free at the

distant end, the leakage was still 110, or sensibly the same. (Fig. 71.)

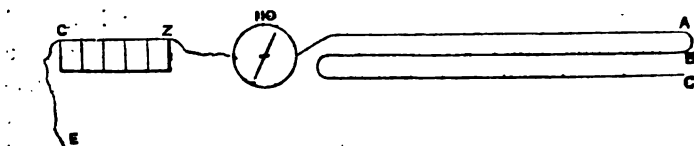


FIG. 71.

The leakage of the three wires, when connected at the testing end, and left free at the distant end as in fig. 72, was 110, or sensibly the same as in Fig. 71.

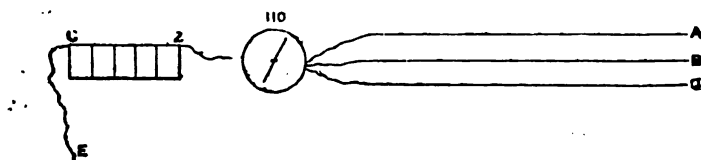


FIG. 72.

But on a wet day, three similar wires, whose respective leakages were 196, 185, and 141, making a total of 522, gave a test of only 476, when looped as in Fig. 71; the distant portions of the wire being tested in reality by a current weakened by the leakage in the nearer portions.

330. The increased leakage of a thick wire arises partly from the surface in contact with its supports being increased by the increased size of the wire itself, and that of the binding by which it is fastened, which is necessarily stronger.

For instance, to take actual results obtained upon wires whose insulation is probably below the average, as they run for a considerable distance near the sea.

In fine weather both wires tested alike, their insulation resistance being 79 million ohms per mile. On a very wet day, for a portion of the same distance the No. 4 had $R = 70,000$, and the No. 8 = 78,000.

Insulation Tests of Two Wires, on the same poles, between Dublin and Belfast—tested at Dublin.

Date.		WEATHER.		Insulation per mile No. 4 wire.	Insulation per mile No. 8 wire.	Remarks.
		At Dublin.	At Belfast.			
1868.						
February	8	Dull	Fine	682,500	787,500	
"	7	Damp	Damp	131,200	157,500	
"	15	Dull	Fine	2,100,000	2,100,000	
"	10	Damp	Fine	210,000	315,000	
"	24	Damp	Dull	91,900	112,900	
"	29	Fine	Damp	787,600	787,500	
March	11	Wet	Rain	157,500	210,000	
April	11	Fine	Fine	38,750,000	38,750,000	
"	8	Wet	Damp	525,000	1,050,000	
"	7	Damp	Misty		787,500	
"	5	Fine	Fine	78,750,000	78,750,000	
June	6	Dull	Misty	921,300	921,300	
November	23	Damp	Fine	658,300	918,500	
"	25	Wet	Rain	131,000	183,800	
December	28	Damp	Damp	1,312,600	1,365,300	
"	21	Rain	Rain	181,300	131,300	Working well.
Maximum insulation per mile No. 4 gauge						78,750,000
Minimum		"	"			= 91,900
Maximum		"	"	No. 8 gauge		78,750,000
Minimum		"	"	"		= 112,900

331. When a wire is tested for conductivity by putting the distant end to earth, the result is apt to be interfered with by earth currents which aid or oppose the testing current. So much is this sometimes the case, that it is impossible to ascertain the true metallic resistance of some circuits by this method.

When the earth currents are not very strong, that is when they indicate upon the instrument used only a few degrees of deflection, and are steady without variation, their effect can be eliminated by taking the mean of measurements made with copper (positive) and zinc (negative) currents; and with a differential galvanometer they can be counteracted by taking the

deflection given by the earth current as the *zero* of the instrument instead of 0°.¹

332. The *loop method*, where the wire is disconnected from earth and looped with another similar wire or one of known resistance, is more accurate; but unless this test is made in fine weather, the leakage from one wire to the other and to earth at each insulator tends to decrease the apparent resistance of the loop.

To remove the latter cause of error, the battery should be insulated, or at all events neither pole should be put to earth. To give an illustration: Two wires on the same poles disconnected and looped at the distant end had a resistance of 6,475 ohms, when tested thus—zinc to one line-wire, copper to galvanometer, galvanometer to the second line-wire,—being in this case disconnected entirely from earth. But when the zinc pole and the line wire attached to it were put to earth, the apparent resistance fell to 5,250 ohms. The resistance of insulation (one wire disconnected) was 9,250 ohms, and the weather was damp.

FAULTS IN THE APPARATUS OR LINE WIRE.

The following are the principal faults of a circuit:—

333. *Disconnection*, or loss of continuity, when the circuit is *broken*, so that the current will not pass. When a current is sent on the line-wire, the galvanometer needle at the sending station does *not move* at all.

When the resistance is *increased* by a rusty or badly-soldered joint in the wire, or dirt at the contact points of the apparatus less current than usual leaves the sending station, and the needle of the galvanometer at either station *moves less strongly*. This is called *partial disconnection*.

334. *Earth*. When the wire *touches the ground*, or some conductor in connection with the earth, such as a tree wet with rain, another line-wire, a stay wire, or the like, or when insulation is very defective, the current passing out from the sending station is always increased; the galvanometer is deflected *more strongly* than usual, because the resistance of the circuit is *lessened* by an extra path or *derivation* being opened to the current, which splits

¹ Another method is given in the Appendix.

between its own wire and the fault in the inverse ratio of their resistances.

But the current received at the stations beyond the fault is

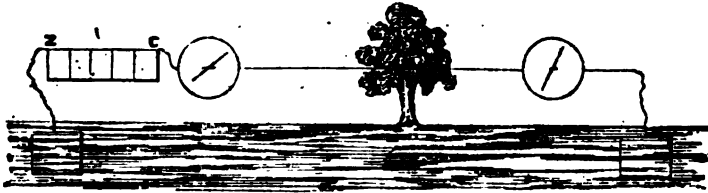


FIG. 73.

weakened, because part is led away by the fault. This is called *partial earth*. (Fig. 73.)

When the resistance of the fault is so low compared with that of the wire beyond, that no sensible current passes to the distant station, the galvanometer of the sending station is very strongly deflected, but that of the distant station remains unmoved. This is called *dead earth*. (Fig. 74.)

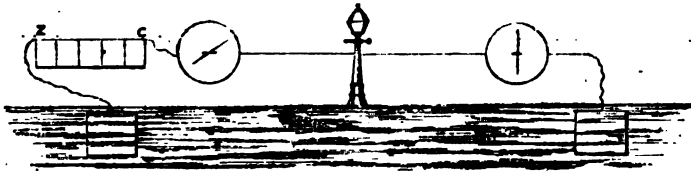


FIG. 74.

335. *Contact*.—When one wire touches another, the current divides at the fault between the three paths open to it. (Fig. 75.)

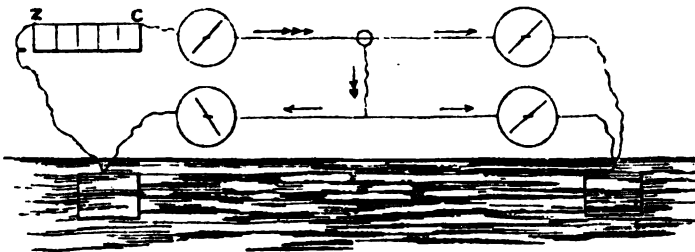


FIG. 75.

When a contact exists between two or more wires *leading into the same office*, if one of the instruments be worked, part of the current returns by the other wires, and causes their instruments to move also, but in a contrary direction. Another part goes on to the distant station by the wire on which it was originally sent, and the remainder to the distant stations by the wires in contact with it, moving the galvanometers connected with them in the same direction as that of the instrument on the original wire. When there is contact with a wire *not leading into the testing station*, the fault will appear to be *earth*.

336. *Weather Contact*.—In wet weather, the moisture which covers the insulators enables the electricity to leak or escape from one wire to another, and to the earth. The current entering the other wires produces effects similar in appearance to, though less in amount than those caused by actual metallic contact between the wires. This fault is called "*weather contact*," and may be prevented by providing a good earth wire (226), so fixed as to intercept the current in its transit from one insulator to another, and convey it to the earth.

The signals at the *sending* station will appear stronger, while those at the *receiving* station will be weakened, as in the case of partial earth.

337. *Defective Earth Connection*.—When the earth wire or plate is defective, and offers a sensible resistance, a current sent on any one wire connected to it divides itself among the remaining wires, making them appear to be *in contact*, because it is usual to connect all the circuits of a station to one and the same earth wire, which is led to the earth plate.

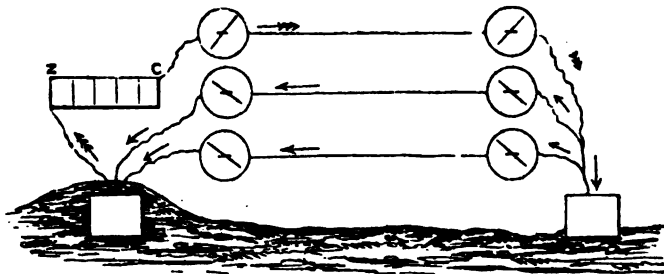


FIG. 76.

In Fig. 76, the right-hand earth is supposed to be defective, and the arrows show the path of the current dividing itself between the earth and the wires.

When the defect is small, it may be mistaken for "weather contact;" but the leakage from one wire to another, from damp or want of insulation, is always *greatest in wet weather*, while the apparent contact from defective earth is *greatest in dry weather*, because damp increases the conducting power of the soil and improves the earth.

In Fig. 77, the earth-wire is supposed to be broken; in this last case no current will pass to the earth at all, even at the receiving end, because the earth forms no part of the circuit.

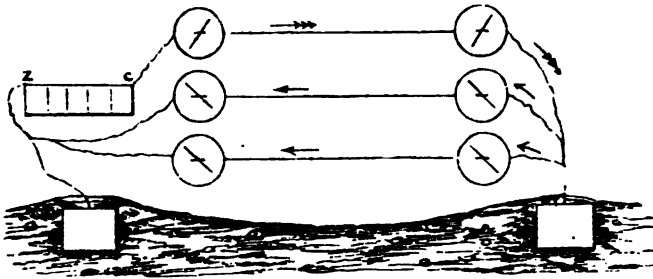


FIG. 77.

TESTING FOR FAULTS.—*First make sure that the defect is not in your own station.*

338. *Loss of continuity.*—When your galvanometer does not move, or moves but feebly when you press the key of your instrument, put earth on at the test-box; should it still remain unaffected or move but feebly, the fault is in the office, being either disconnection of a wire, failure of the battery, a break of continuity caused by dirt in the apparatus, or loss of power in the needle or other permanent magnet.

To test the office connections, first try if the batteries produce a current by putting a detector in circuit between the two poles, or between the battery terminals of the instrument, or touch these terminals with one finger of each hand, so as to feel the shock. If the batteries are faulty, test them trough by trough

and cell by cell by a *quantity* detector (71), till the fault is discovered ; then remove the faulty battery, or connect it across with a wire.

Should the batteries be found in order, connect a piece of wire known to be good to the instrument terminal of the test-box, and with it touch successively the several connections and parts of the apparatus, commencing with the one nearest the test-box. When the needle moves, the fault has been passed, and will be found between the point last touched and the one touched next before it.

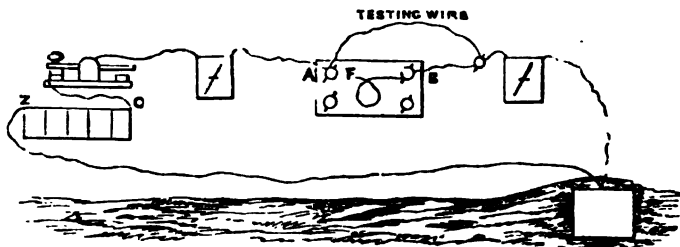


FIG. 78.

Let the wire of the relay A F B be broken at F ; touch the terminal B with the testing-wire, the needle is unaffected. Touch A, and it moves, because the broken place has been bridged over.

Lacquer or dirt in a key or relay will often cause disconnection, especially at the stop upon which the key of a printing instrument lies, or the bridge which connects the springs of a needle instrument.

If best salad oil be applied to the pivots and points of contact of keys, the dirt will never harden sufficiently to break the connection. A film of oil secures a better contact than a dry surface.

It must be recollected that a strong current will pass an imperfect connection, while a weaker current would be stopped by it. Thus it frequently happens that a dirty key will transmit signals perfectly well when the circuit is shortened by putting earth on, while no current will be sent at all when the entire

line is open. In all tests for loss of continuity, a very feeble current should therefore be employed. Use one or two cells only.

339. If all the connections appear in order, try if the magnetism of the needle is enfeebled, and restore it by the means described in the chapter on magnetism.

340. If after putting earth on at the test-box your galvanometer needle moves strongly when a feeble current is sent from the key, the loss of continuity is on the line, or in the leading-in wires; it is better now to test from the test-box, but at small stations having no test-boxes the instrument galvanometer and key may be employed.

The cause of the fault may be a broken wire, a faulty joint; or a wire removed from, or a fault in a distant instrument.

Put a good galvanometer in circuit at the test-box, and send a current to line in the manner shown by Fig. 63. If the needle does not move, the line wire is broken or disconnected at a distant station; if it moves feebly, the resistance of the circuit is increased by a faulty joint in the wire, or an imperfect connection in an instrument.

A. Suppose the loss of continuity to be total, and to lie between station B and station C. (Figs. 79 and 80.)



FIG. 79.

Send a current to line through your galvanometer and instruct A, the nearest station, to put earth on without disconnecting the wire, and to inform you when he has done so.

Your needle will now be deflected.

Let A remove the earth and let B put it on (fig. 79), your needle will remain deflected, but when B has removed the earth and C has in his turn put it on (fig. 80), the deflection will cease because the fault has been passed.



FIG. 80.

341. Except in very fine weather, or when insulation is exceptionally good, it will be found that as the distance to which the test extends, increases, more and more current passes out to line from the testing battery, because of the leakage at the insulators, and if the daily testing of the wire for insulation (earth) has been duly registered, an approximate guess at the distance of the break may sometimes be made from the amount of leakage from the wire.

In very fine weather, and on a very good line, the amount of return current received from the wire when a strong current is sent, and the line instantly put to earth through a galvanometer, will show if the fault be near or distant. A printing machine shows the return current readily. (150.)

342. B. When the defect in continuity is but *partial*, much greater care is needed.

Send a weak current on the line through the galvanometer and let earth be put on at each successive station as before, until two stations are found, at the nearer of which the earth makes a *great* difference, and at the more distant of which it makes a *very slight* difference in the deflection. The fault will lie between them.

As some current passes the fault in each case, so much may

pass, even when the earth is put on *beyond* the fault, as to deceive the tester, if a strong current be used.

- When a wire is broken, and lies on the ground, it occasionally, though rarely, tests as if partially disconnected, the soil conducting the current over the break.

343. When a wire has more resistance than is due to its length there is probably a faulty joint, which should be made good.

When the section in which the fault lies has been found, the joints can be tested without interfering with messages, by connecting a wire to each end of the joint, and placing a single cell and a vertical detector in circuit between them, so as to send a current through the joint. The apparatus must be *insulated* by being placed on a tripod or a staff, and the wires may be attached by two rods furnished with spring hooks to clasp the line-wire; care must of course be taken that the line wire is clean, and the hooks may be roughened that they may scrape it.

344. *Earth*.—In this case when the key is pressed the instrument galvanometer moves as strongly, or even more strongly than usual; but signals do not reach the distant instruments.

To test the office, disconnect the instrument wire at the test-box; if the galvanometer is still deflected, there is earth between the instrument and test-box, the place of which can be found by breaking contact successively at the several available points, until the deflection ceases.

. Should the galvanometer deflection cease, the fault is beyond the test-box, and may be searched for by sending a current through the test-box galvanometer to line as in Fig. 63.

Should the resistance of the wire be about the same as usual, and the needle move about as strongly as in the usual daily tests for resistance, the fault is *earth* at or very near the distant terminal station.

Should the needle be more strongly deflected than usual, the fault is near the testing station.

Let the fault be between stations B and C.

Let A disconnect the wire, the deflection of the testing galvanometer, G, will cease, because the circuit is broken. (Fig. 81.) Let A reconnect the wire, and let it be disconnected at B and

c in turn. When B disconnects, the result will be the same as

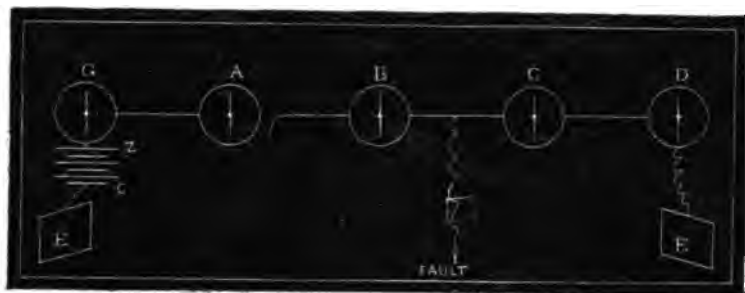


FIG. 81.

before, but when c disconnects (Fig. 82), the galvanometer will remain deflected, because all or almost all the current will go to



FIG. 82.

earth at the fault, unless it has great resistance, in which case the deflection will be considerably decreased.

345. Disconnection and earth may be tested for by instructing each station in succession to send you a current, and trying if it reaches you. This method is not certain, as many persons can unscrew a wire, so as to disconnect it, but are not to be depended on to send a current. Besides this—

Disconnection and earth also are not always total, so that a feeble current may reach you from a distant station, even

when there is partial earth between that station and your own, or when there is partial disconnection.

346. If you have no means of speaking direct, send a message by some other route, instructing the station to disconnect or put earth on the wire at a certain time, for five (or fewer) minutes. Thus: "Disconnect — circuit from 10.20 to 10.25: say if you will do so. Time 10 A.M."

The reply should be, "I will disconnect — circuit from 10.20 to 10.25 A.M. Time 10.5 A.M."

347. *Contact.*—When a current sent on one wire returns by another, and moves the apparatus connected with it, disconnect one of the instrument wires from its line-wires at the test-box, and send a current from the instrument key. If the other instrument still moves, the fault is in the office, and may be traced by successive disconnections, as in the case of an earth. If the contact ceases, the fault is on the line. Suppose that it is between B and C.

Disconnect both line-wires at the test-box, send a current on one, and place the galvanometer G in the other.



FIG. 83.

Instruct station A to disconnect either of the two wires, and to say when he has done so; the deflection will cease, showing the fault to be beyond A. Instruct A to join up, and B to disconnect; the same result will follow.

But when C disconnects (Fig. 84), the deflection will remain as before, or be slightly less if the fault have a sensible resistance,

showing that c is beyond the fault. Care must, of course, be



FIG. 8A.

taken not to be deceived by "weather contact," or the ordinary leakage of one wire into another.

348. *Never test for contact by having the earth put on at the testing stations: this method is liable to great error, and has led to much inconvenience.*

If a *very good* earth be put on *beyond* the fault, and very near it, it may cause the contact to disappear almost entirely, because the resistance of this new path may be very much less than that of the other wire. And if the earth be *imperfect*, and be put on between the original station and the fault, the contact will not disappear; especially if the wires be clean, so that the resistance of the point of contact is but slight, or if the wire beyond it is short.

The resistance will certainly be decreased in a measure, and therefore the deflection of the testing galvanometer will be larger; but unless the instrument is sensitive, and the testing battery not strong enough to deflect the needle to its full extent, the variation in the resistance of the circuit may escape notice.

And, moreover, an unskilled person may be trusted to disconnect, but not to put earth on.

349. When a contact occurs between the two wires of a branch line forming a loop of the main circuit, it will appear like an earth to the stations upon the branch, while the other stations would report inattention at branch stations, because

they would be able to speak to all stations except those on the branch.

350. *Intermittent faults.*—When an intermittent fault does not continue long enough to be tested for, let the faulty wire be *crossed* at your station, and at another, with a good wire, thus:—

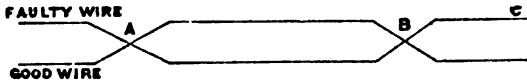


FIG. 85.

If the fault shifts to the other circuit, it will lie between A and B, the stations at which the wires are crossed.

If it remains on the same circuit as before, it is beyond B.

Let the wires be *crossed* at C, and *put straight* at B, and so on, station by station, till the fault shifts, when it will be found between the two stations at which the wires were last crossed.

To *cross* wires means to interchange them, as shown in the above diagram. To *put wires straight* is to restore them to their original places.

351. When it is required to test from an intermediate station, the first step is to put the earth on, first on one side the apparatus, then on the other, in order to find which section is defective. So long as the earth is on, the station is, in fact, terminal, and the previous rules apply.

352. When the section of the line in which the fault lies has been determined by one of the preceding methods, it can generally be seen by the line-man. But should it not be visible, it must be tested for on the line, thus:—

353. *To test for earth:*

Let an inspector put a current on at the station, and walk out on the line with a detector, after having disconnected the wire at the other end. Let the detector be placed between wire and earth; if the current passes, the fault will be still farther distant. This test must be repeated at different points until the current ceases or greatly diminishes. If the weather and the insulation be bad, allowance must be made for the gradual weakening of the current caused by the leakage at the posts.

When the fault is passed, the current will either cease altogether or be very much weakened.

If the detector offers but a slight resistance, sufficient current may pass by it to deflect the needle, even after the fault has been passed. It is desirable, therefore, to make the resistance of the detector greater than that of the line to be tested.

Or the inspector may take a small battery on the line, after having insulated the circuit at both ends; he can then disconnect at any convenient place, and test both ways.

354. Disconnection may be tested for in a similar way, by putting earth on at both ends of the wire, instead of disconnecting it; or a current may be put on at the station and sought for with a detector, as in the previous case, taking the precaution to insulate the distant end of the wire, lest another station interfere with the tests.

The inspector may arrange with the clerk in charge of a station to disconnect, to put earth on, or to make a test at a certain fixed time.

When a fault is reported to exist on *both sides* of a station, it is almost always at the station itself, generally in the leading-in wires.

355. It is evident that when two wires are faulty, but in different sections, the good portions of each may be connected together, and the defective portions disconnected, so as to form one perfect wire out of the two.

METHODS OF FINDING THE DISTANCE OF FAULTS.

356. The principle upon which the different methods of *distance testing* are founded is the finding the resistance of the line-wire, between the testing station and the fault, by means of the Wheatstone's balance, or the differential galvanometer and the resistance coils.

The difficulties which present themselves are the varying resistance of the fault itself and the absence of a correct determination of the true resistance of the several portions of the

circuit, including, as many circuits do, apparatus and portions of wire of a different gauge and different conductivity.

If periodical testing has been carefully carried out, the latter data will in many cases have been accurately determined, but the resistance of the fault will vary in each individual case. An earth, for instance, may vary from *dead earth* with no resistance to a resistance equal to ten miles of the line-wire, or even more; however, many of the processes to be described are independent of this resistance altogether.

357. *To find the distance of an earth.*—The *loop-test* is the most accurate, and should always be adopted whenever a second wire is available, because it is not affected by a variation in the resistance of the fault. Shorten the length to be tested as much as possible, and let all the instruments in circuit be taken out. Choose a good wire, one free from fault, and similar, if possible, to the wire to be tested. Insulate both from earth at the nearest available point beyond the fault, and let them be connected together there in a loop, insulated from earth.

Let A B be the perfect wire, and O B the faulty one, connected together at B, the fault being an earth at F.

Two tests must be made, the first to find the resistance of the entire loop; the second to find the difference in resistance of the portions on either side of the fault, or how much must be added to the shorter portion to make its resistance equal to that of the longer.

358. *To test by the differential.*—(a) *Take off the earth at the testing station,* connect one end of the loop to one pole of the battery, the other end to one coil of the differential. Connect

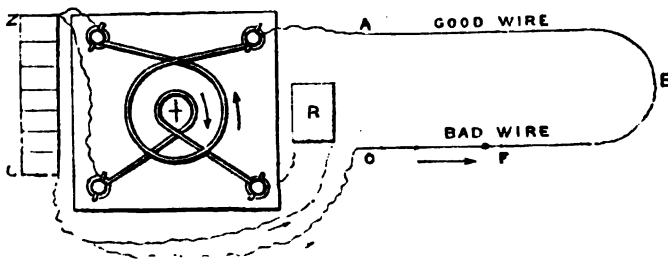


FIG. 86.

the same pole of the battery to the resistance R , the other end of R to the opposite end of the other coil of the differential, and the other pole of the battery to both the unoccupied terminals of the differential, so that the current may divide between the loop and the resistance R , passing round the two coils of the differential in opposite directions. Alter the resistance of R until the needle is balanced; the reading of R will then show the resistance of the loop.

(b) The next step is to find how much resistance must be added to the faulty wire to make the two portions of the loop, $A B F$ and $O F$, balance one another.

Put the copper pole of the battery to earth.

Connect the zinc to the terminal of one of the coils of the differential, and also to the opposite terminal of the other coil, by a short and thick wire, as in the former test.

Connect the perfect wire $A B$ to the unoccupied terminal of one of the coils of the differential.

Place the resistance coils R between the faulty wire and the remaining terminal.

The positive current will enter the wire by the fault, through the earth, and will divide at the fault F ; as the distance and resistance between O and F is less than that between A and F , the current in $O F$ will overcome that in $A B F$, and move the needle. Resistance must be added to $O F$ at R , until the needle no longer moves when contact is made and broken repeatedly.

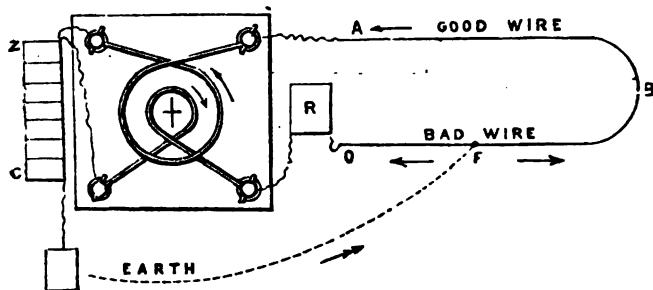


FIG. 87.

with the battery wire Z . The resistance $R O F$ will now be equal to $A B F$.

Let L =	the resistance of the whole loop	$A B F O$
" R =	" added to $O F$ to make it equal to $A B F$	
" x =	" the longer portion	$A B F$
" y =	" the shorter portion	$F O$

Then as $x + y = L$, and $y + R = x$,

$$L = 2 y + R, \text{ and } y = \frac{L - R}{2}.$$

359. If the resistance of the wire is uniform throughout, y divided by the resistance per mile will be the distance of the fault from the testing station: that is to say, the resistance of the loop in the first test less the resistance added to $O F$ in the second test, by means of the coils R ; and divided by 2, is the resistance of the portion $O F$.

Thus, supposing the resistance of the loop to be 1,000 ohms, and that 100 ohms have been added to the faulty wire to balance the needle.

Then $\frac{1000 - 100}{2} = 450$ ohms, the resistance of the portion of the *faulty* wire between the galvanometer and the fault.

If the loop of 1,000 ohms measures 120 miles; then by proportion, $1000 : 120 :: 450 : 54$ miles the distance of the fault,

$$\text{or } \frac{120 \times 450}{1000} = 54.$$

360. We have here supposed the resistance to be uniform throughout the entire circuit; but if a part of the line differ in resistance from the rest, as when there are buried wires or thinner wire over houses, the resistance of each part must be calculated separately; in fact, the resistance of each part of the circuit should be ascertained, if possible, from the periodical resistance tests, for no two samples of iron or copper wire agree exactly in conducting power, or even in gauge. For instance, suppose that in the circuit of 60 miles there is a mile of buried wire whose resistance is 30 ohms, next the testing station, the remainder of the wire having a resistance of 10 ohms per mile; and that 100 ohms have been added to the shorter arm of the loop to balance the needle, the total resistance of the loop being 1,240 ohms;

this total resistance would then be composed of the following:—

59 miles of 10 ohms = 590 ohms

1 mile of 30 „ = 30 „

Total . . . 620

which, doubled for the loop, makes $L = 1240$ ohms

$R = 100$

then $\frac{L - R}{2} = 570$, the distance of the fault *in resistance*.

But of this resistance, 1 mile = 30 ohms, leaving 540 ohms at 10 ohms the mile, or 54 miles of ordinary wire; adding the 1 mile of buried wire, gives 55 miles, the actual distance.

361. If R is not sufficient to measure the resistance, that coil of the differential to which it is attached may be shunted, in which case the reading must be multiplied by the value of the shunt. For instance, if the shunt be equal in resistance to the galvanometer, the reading must be doubled.

362. If the wire used to form the loop is neither of the same gauge as the faulty wire, nor uniform in resistance throughout, the test will still be correct if the total resistance of the loop is known, because the object of the test is to find how much resistance must be added to the shorter portion of the loop to make it equal in resistance to the longer, and the question of resistance as affecting the length of the several portions of the wire appertains to the shorter portion only between the testing station and the fault.

363. The copper pole of the battery is put to earth, and as the fault itself is earth, the earth acts as if it were a wire connecting the battery with the fault F . The resistance of the fault will therefore not affect the test except so far as to alter the battery power required to produce a sufficient deflection of the galvanometer.

364. *To test with the bridge.*—(1.) First find the resistance of the loop L , then (2), the resistance of the portion of the faulty wire lying between the testing station and the fault.

(1.) The arms A and C may generally be made equal: 1,000 ohms in each will be found a convenient resistance. The

variable resistance, R , by which the balance is effected, forms arm B , and the loop L the fourth arm D .

Then by the law of the bridge¹ $A : C :: B : D$, so that $D = \frac{B C}{A}$, or $L = \frac{R C}{A}$.

But if A and C are equal, as in the case under consideration, then $D = B$; or the resistance of the loop is read directly from the resistance coils R .

But if A and C were not equal, L would be greater or less than the reading of R , in the same proportion as A was greater or less than C ; or $L = \frac{R C}{A}$.

(2.) The bridge is arranged as in Fig. 88 :—

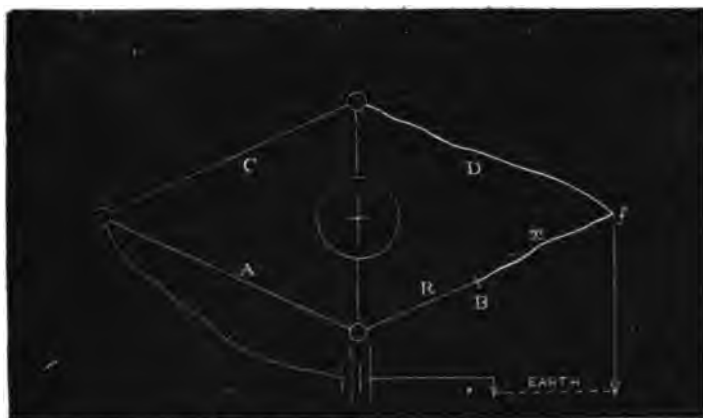


FIG. 88.

Here A and C are fixed resistances, as in (1); D the longer portion of the loop; f the fault. B is made up of x the shorter portion of the loop, and of R , the resistance to be added to it to balance the longer portion.

Then $\frac{A L - C R}{A + C} = x$, the distance from the testing station to the fault.

Let $L = 1500$, R (the reading of the resistance coils in B)

¹ See the note at the end of the chapter.

≈ 13900 , $A \approx 1000$ and $c = 100$; then, substituting these figures for the letters in the formula, we have

$$\frac{(1000 \times 1500) - (100 \times 13900)}{1000 + 100} = 100, \text{ the distance of the fault.}$$

But if A and c are equal, as will generally be the case, 1,000 in each being, as in (1), a convenient resistance, the formula is much more simple; for then $\frac{L - R}{2} = x$.

In the example last given, the reading of R , the difference of resistance between the two portions of the loop, will now be 1300, and $\frac{1500 - 1300}{2} = 100$.

(3.) The bridge may be so arranged as to show the *ratio* which the portions of the loop on either side the fault bear one to the other. In order to obtain a large range of resistance, the arms A and c are constructed of sets of coils similar to those used in arm B .

The arrangement is shown by Fig. 89, D being the longer portion, and B the shorter portion of the loop.

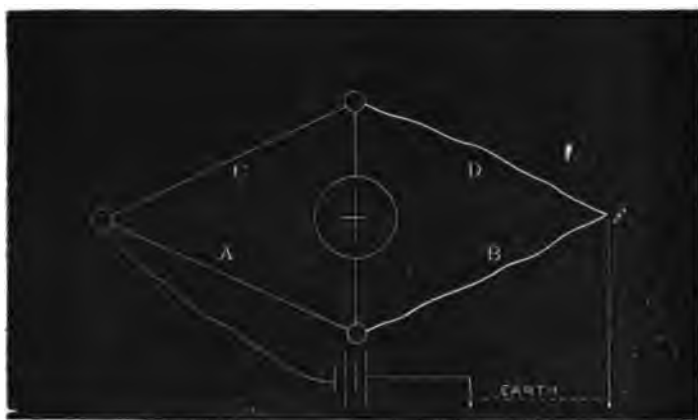


FIG. 89.

The copper pole of the battery is put to earth.

$$\text{Then } B = \frac{L A}{A + C}.$$

For example, let L be 1,500, and let the resistances of A and

C, when a balance has been obtained, be 70 and 980 respectively; then

$$70 + 980 : 1500 :: 70 : B$$

$$B = \frac{1500 \times 70}{70 + 980} = 100$$

as in the previous example. For as B and D, which together make up the entire loop of 1,500, are in the proportion of 1 to 14 (100 to 1400), A and C must be in the same proportion also. ($70 \times 14 = 980$.)

365. *When a second wire is not available*, the approximate distance of a fault may be found by testing from each of the stations at the extremities of the faulty length. But as the resistance of the fault itself is included in both tests, and may vary in the interval between the tests, the method is not as certain as the last-mentioned.

Let the wire be tested at each end in turn, while disconnected at the other; each test will give the resistance of the wire between the testing station and the fault, *plus the resistance of the fault itself*. To find the resistance of the *wire* between either station and the fault, *add* the resistance found by the test made at that station to the resistance of the line between the stations when perfect, *deduct* the test made at the distant station, and divide the result by 2.

It will readily be seen that as both tests make the distance too great by the amount of resistance in the fault itself, if we *add* too much in the first case, and in the second *deduct* exactly an equal amount too much; we get rid of the resistance of the fault although we do not know what is. We can easily find it if we please, but it is not necessary to do so.

If A and B are the stations, *a* the test made by A, the wire being disconnected at B; *b* the test made by B when A has disconnected; *L* the resistance of the wire itself as ascertained by the periodical tests, $\frac{a + L - b}{2}$ will be the *resistance* between A and the fault, which can be reduced into miles by proportion, should the wire be uniform throughout; and $\frac{b + L - a}{2}$ the resistance between B and the fault.

366. The following method is not so accurate as either of the former, and is not independent of the resistance of the fault.

(1.) Let the wire be *disconnected* at the first station beyond the fault; measure its resistance.

(2.) Let it be *put to earth* at the same station, again measure the resistance, which will be less than before, because there are now two roads open to the current, viz. the fault, and the wire beyond the fault.

(3.) Subtract the second resistance from the first.

(4.) Subtract the resistance when put to earth (2) from that of the wire when in good order, as given by the record of periodical tests.

(5.) Multiply these two remainders (3 and 4) together, and extract the square root of their product. Subtract this square root from the resistance when put to earth (2), and the remainder will be the resistance of the wire between the testing station and the fault.

For example: Suppose there is a partial earth on the line whose resistance, when in good order, is 280 ohms;

(1.) And that the resistance when disconnected = 400 ohms

(2.) When put to earth = 240 „

(3.) Difference = 160 „

(4.) And the difference between 240 and 280 is = 40 „

(5.) The two remainders multiplied = 6400 „

The square root of 6,400 is 80 ($80 \times 80 = 6400$), which deducted from the resistance when put to earth, leaves 160 units as the resistance of the wire between the testing station and the fault.

The principle of this test is this—

When the wire is *disconnected* at the distant end, the current which leaves the battery will go to earth at the fault, and the resistance (r) found by the test (1) will be that of the wire (x)

between the galvanometer and the fault, added to that of the fault itself (z);

Therefore $r = x + z$ (Fig. 90.)

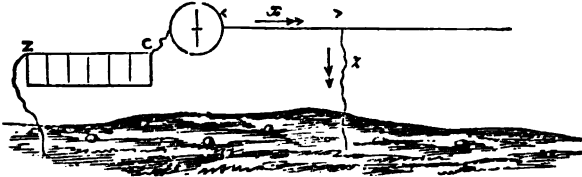


FIG. 90.

When there is *dead earth*—that is, a fault offering *no resistance*—the wire will test precisely the same whether disconnected or not, and its resistance will give the distance of the fault at once. Here $z = 0$, and therefore $x = r$.

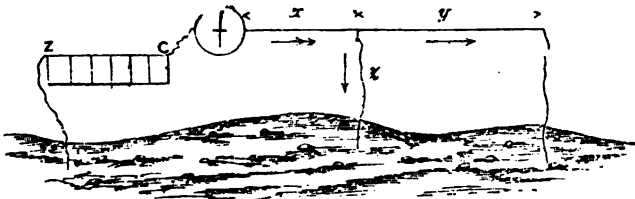


FIG. 91.

When the wire is *to earth* at the distant end (Fig. 91), the current will divide itself between the fault and the wire beyond the fault. The resistance (r') found by test (2) will be that of the wire (x) between the galvanometer and the fault, and the joint resistance of the fault (z) and the wire (y) beyond the fault, or $r' = x + \frac{y z}{y + z}$ (242).

And when the wire is in good order, its resistance (L) is, of course, that of its two parts, x and y .

$$\text{Then } r = x + z. \quad L = x + y.$$

$$r' = x + \frac{y z}{y + z} \quad x = r' - \sqrt{(r - r') \cdot (L - r')}.$$

367. *To find the distance of a contact.*—The two wires in contact will be of course *looped* at the point of contact; and

provided they are clean and are so twisted that the junction offers no resistance, may be disconnected at the nearest point and tested as a loop for resistance; half this resistance will then be the resistance of the wire between the galvanometer and the fault, and from it the distance can be calculated in the manner already explained.

368. But it is seldom that a metallic contact is perfect, nor can it be known with certainty whether the junction of the two wires offers resistance or not. It is better, therefore, to treat the fault as an *earth*, and to test one of the wires, or both in turn, for earth, by one of the methods already described, using the other as a battery-wire.

The most convenient bridge-test will be a modification of (3) page 204; for as the distance of the contact is yet unknown, the tester cannot decide beforehand which is the longer and which the shorter portion of the loop.

Two wires, $g F h$, and $l F m$, suspended on the same poles, are in contact at F (Fig. 92). The resistance L of $l F m$ is first found, or obtained from the record of periodical tests.

The arms A and C are arranged as in test (3), the distant end, h , of $g F h$ is *disconnected* at the distant station; the nearer portion $g F$ is used as a battery-wire between the testing station and the fault F .

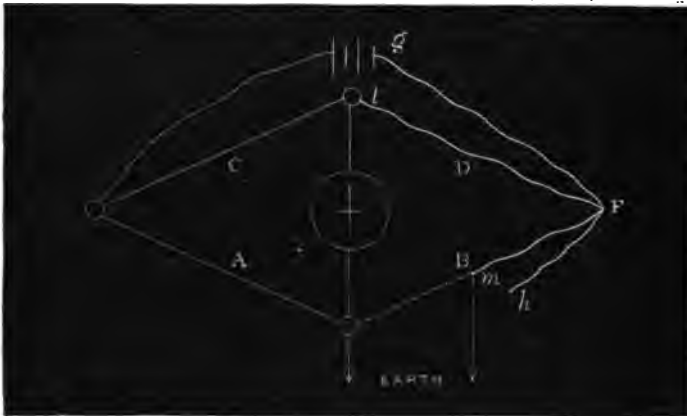


FIG. 92.

The portion $l f$ of the second wire, that is the portion lying between the testing station and the fault, forms the arm D. The end m is *put to earth* at the distant station, the point of junction between the arms A and B is also put to earth; this being so, the arm B is formed of the distant portion, $f m$, of the second wire, and the earth between the two stations whose resistance is nothing. B is then virtually composed of the distant portion of the wire alone.

When a balance has been obtained by the adjustment of the resistances in A and C, the value of $m f$ (B) is found by the formula $B = \frac{l A}{A + C}$ as in bridge-test (3).

The places of the two wires may be exchanged, and the distance found by testing $g f h$, as a check.

369. The differential galvanometer may be used thus (Fig. 93) —The two wires $g f h$, and $l f m$ are in contact at f , the end h of the first is disconnected at the distant station, and the end m of the second is put to earth there; the portion $g f$ of the first wire is used as a battery-wire as when testing by the bridge.

Connect one end of each of the galvanometer coils to the copper of the battery, the opposite end of one of the coils to earth, the opposite end of the other coil to the end l of the second wire, and the zinc to the end g of the first wire, whose distant end, h , is disconnected.



FIG. 93.

The current flowing along the battery-wire gf will divide at f , one portion passing forward to earth at the distant end of m , and reaching the galvanometer through that coil which is connected to earth; the other part will return to the galvanometer through the *nearer* portion of N . No part of the current will flow through fh to the distant station, because the wire is insulated there.

If the fault is exactly in the centre of the wire lfm , the galvanometer needle will not move, as the currents in the coils will balance one another; but if one section is longer than the other, resistance must be added between the wire and the galvanometer, or between galvanometer and earth. If the fault is on the *near* side the centre of the line, resistance will be added to the wire at l ; if on the *distant* side the centre, the resistance will be placed between galvanometer and earth, for this will be tantamount to adding it to the distant portion of lfm , which is itself to earth at the distant station.

The resistance which it may be necessary to add to the shorter section to balance the needle will indicate by how much its resistance is less than that of the longer section. Let L be the total resistance, x that of the shorter portion, $L - x$ that of the longer, and R the resistance added to the shorter;

$$\text{Then } x = \frac{L - R}{2}$$

Or subtract the resistance placed in the shorter section from the total resistance of the wire, and divide by 2.

NOTE.

370. (a) Formula $\frac{A L - C R}{A + C} = x$, bridge-test (2). Page 203.

Let D be the resistance of the arm D , or the longer portion of the loop; x the resistance of the shorter portion; R the reading of the resistance coils after a balance has been obtained, which resistance, together with x , makes up the arm B (Fig. 88); A and C the fixed resistances of the bridge; and L the resistance of the whole loop, then—

$$B = R + x$$

$$D = L - x$$

and as $A : C :: B : D$ or $A D = C B$;

substituting the values of B and D , $A (L - x) = C (R + x)$

$$\text{and } \frac{A L - C R}{A + C} = x.$$

Again, when A and C are equal, the letter A may replace C
the formula now reads $\frac{A L - A R}{A + A}$ or $\frac{L - R}{2} = x$.

(b.) Formula $\frac{L A}{A + C}$ in bridge-test (3). Page 204.

A balance having been obtained,

$$A : C :: B : D ;$$

but $B + D = L$ the total resistance of the loop ;

therefore $D = L - B$, and $A : C :: B : L - B$;

$$A L - A B = B C \text{ and } A L = B C + A B.$$

$$A L = B (A + C) \text{ and } B = \frac{A L}{A + C}.$$

Suppose $L = 1500$, $A 7$ and $C 8$. Now L is to be divided into two portions, which must in this case be in the proportion of 7 to 8. We divide it into 15 ($7 + 8$), equal parts, and apportion 7 of these parts to the portion which bears a relation to A , for the distance of the fault.

TECHNICAL TERMS IN COMMON USE.

371. *Line*.—The wire connecting one station with another.

Circuit.—The wires, instruments, &c., forming the path for the passage of the current.

Local circuit.—One which includes only the apparatus in the office, and is closed by a relay actuated by the line current.

Local battery.—The battery of a local circuit.

Line battery.—The battery from which signalling currents are sent out to line.

Metallic circuit.—When a return-wire is used instead of the earth, as in the case when two wires are *looped*.

Earth currents.—This term is used to indicate the spontaneous currents in wires which appear to be caused by currents flowing from one part of the earth to another. These earth currents were formerly called “deflections.”

Deflection.—The angle or number of degrees through which the needle of a galvanometer moves when a current is passing through the coils.

Full deflection.—When the needle is deflected to the full extent of its scale.

Terminals.—The screws of instruments, batteries, or test-boxes, to which the wires are connected.

Shunt.—A wire connected across the terminals of a coil, so as to divert a portion of the current.

Return current.—The inductive discharge from a cable or underground wire.

Reverse current.—A current in an opposite direction to that used for producing a signal, or mark,

Reversals.—A succession of alternate positive and negative currents.

To reverse a current.—To change its direction.

To reverse a battery.—To turn it end for end, so as to reverse the current in a circuit.

To short circuit a faulty battery cell.—To join together the plates on each side of the faulty cell by a piece of wire.

To short circuit an instrument.—To connect the “up” and “down” terminals together by a piece of wire, so as to shunt the whole current from it,

To put to earth.—To connect any wire or terminal to the earth-wire at the test-box.

To make, or find, earth.—To be connected to earth. A wire connected to earth is frequently marked thus →.

To disconnect or cut a wire.—To take a wire off its terminal so as to break the circuit, leaving the wire insulated.

To connect up, or join up, a wire.—To replace a wire which has been disconnected.

To loop two wires.—To disconnect them from their ordinary

places, and join them together, thus forming a circuit entirely metallic, so that a current sent from a station on one wire may return to it by the other, and not by the earth.

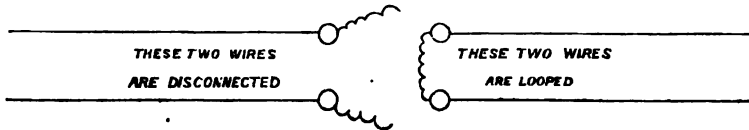


FIG. 94.

To cross wires.—To interchange them as shown by the diagram below—

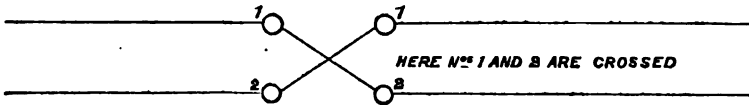


FIG. 95.

A service message to cross two wires should simply state the numbers or names of the wires to be crossed: and the reply to any service message requiring an alteration of the wires should state exactly what has been done, thus :—

Message: "Cross Nos. 1 and 2."—*Reply:* "Nos. 1 and 2 crossed."

To put wires straight.—To restore the *ordinary* arrangement of the wires, or instruments.

All changes should be made at the testing-box and not at the instrument.

To take the constant of a galvanometer.—To ascertain what deflection the battery used for testing would give upon the galvanometer through a certain fixed or *constant* resistance, such as the so-called *standard resistance coil*. 320.

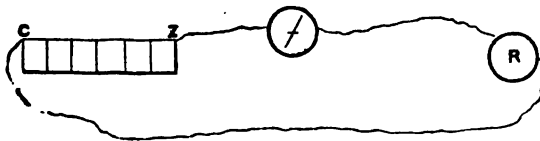


FIG 96.

To shackle a wire.—To cut it and place an insulator between the ends.

Modes of connecting the wires for testing with an ordinary galvanometer.—For insulation or earth, or to send a current on the line :—

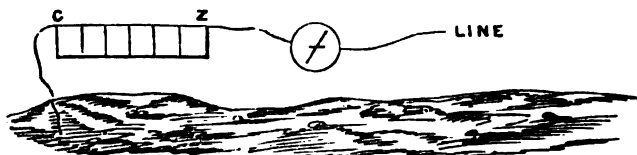


FIG. 97.

For contact between two wires :—

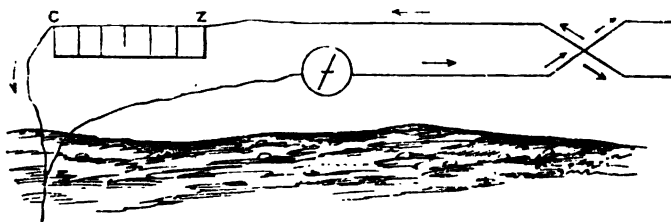


FIG. 98.

To receive a current from another station :—

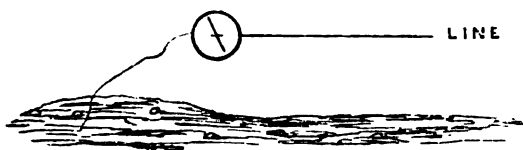


FIG. 99.

Copper always to earth. Zinc to line.

PART IX.

INSTRUMENTS FOR SIGNALLING.

THE NEEDLE INSTRUMENT.

372. The needle instrument is simply a vertical galvanometer (120), with a key or apparatus for placing a battery in circuit, and for reversing the current.

The lower end of the inside needle is a north pole, and the coils are wound so that if the copper of a battery be connected to the left, and the zinc to the right-hand terminal, the top of the needle will move to the right.

The key, when pressed, disconnects the line-wire from the coil, and places the battery in the opening thus formed. When the key is at rest, the line-circuit is continuous, and the battery out of circuit. By reversing its position it reverses the position of the poles of the battery with respect to the divided ends of the line-wire.

The keys of the older needle instruments are constructed as shown in the cuts; the newer form is a pair of levers; the principle of both is identical.

373. When several instruments are connected in circuit, the wire connected to the right hand of the coil in the first must be joined to the left hand of the coil in the second, and so on; so that the current may flow always in the same direction, for the direction of the movement of the needles depends on the direction of the current (116).

Take three instruments, 1, 2, and 3. If the left side of the coil 1 be connected to the earth, and the right to the line-wire

leading to 2, then, to make the current traverse the coil 2 in the same direction, it must enter at the left, and leave by the right; and the line wire coming in from must be connected to the left side of the coil at 3, which, being the terminal station, must have the right side of its coil connected to the earth.

Thus, the *up*-station earth and all the *up*-wires are connected to the *left*, the *down*-station earth and all the *down*-wires to the *right*, and *vice versa*.

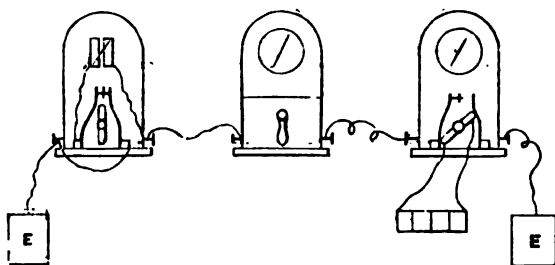


FIG. 100.

The principle is the same, however the instrument may be arranged.

In fixing needle instruments the practical rules are :—

Connect the instrument so that when on short circuit (*i.e.* when the two line terminals are connected by a short wire) the needles move in the same direction as the handles or keys.

After connecting up an additional instrument on a circuit, give the test signals *E T* slowly, making a long pause after *T*, to separate each pair of signals, and to show when the group is commenced, until some station sees the signals and repeats them.

If they are not repeated correctly, your wires are wrongly connected, and must be altered until the signals are received accurately on your own dial. If you receive *T E*, your line and earth-wires must be reversed.

Whenever unintelligible signals are received, the test signals should always be given, in order that the distant station may have a chance of communicating by altering its wires, or that you may see what is wrong, and alter your own wires so as to give any necessary instructions.

If, after connecting two instruments according to the previous instructions, the needles move in opposite directions, either the coils of one have been wound in a reverse direction, or the polarity of one of the needles has been changed.

374. If the line-wires of one of the instruments are reversed, the signals *received* at that station will be reversed also; *forwarded* signals will be read correctly on its own dial, but will be reversed at other stations. If the battery-wires are reversed and the line-wires correctly connected, signals will be *received* correctly at the station; but those *forwarded* by it will be *reversed*, and the needles on its dial will move in the opposite direction to the handles. If both line and batteries are wrongly connected, received signals will be reversed, but other stations will be able to read, because the effect of reversing the line is counteracted by the reversal of the batteries. The needle will still move in an opposite direction to the handles. It is evident that no alteration of the battery wires can affect *received* signals.

375. The faults to which the needle instrument is subject are :—

(1.) Demagnetization by lightning, or the absence of what is called retentive power in the needle, causing the signals to become weak or to cease altogether.

(2.) Reversal, when the poles of the needle are changed by lightning, and the signals appear reversed, as if the batteries were wrongly connected. In both these cases the needle must be re-magnetized (106), and in effecting this care must be taken not to bend the pivots.

These faults can be discovered by putting the instrument on short circuit.

In the most recent instruments the magnetized steel needle is replaced by one of soft iron magnetized by induction from a strong permanently magnetized steel-bar, placed outside the coil. If well made they are very seldom demagnetized, and are never reversed.

(3.) When the needle can be moved in one direction only, one pole of the battery at the station has become permanently connected to the earth, from damp in the battery room, accidental contact of a battery wire or plate with the earth, or a contact

between one of the battery connections inside the instrument and the earth or line, caused by metal-dust worn from the pins or bearings, dirt and oil, or pieces of coil wire broken off. In the case of earth on the battery wire or battery, the needle can be moved one way when the faulty battery-wire is disconnected from the instrument. If the needle can be moved when *either* battery-wire is off, both wires make earth.

(4.) One station is able to speak to all the rest, but no other station can give a signal. This fault will be found at the station which is able to work, and is caused by the circuit being broken by dirt on the points on which the line-springs rest. Moving the handle or key of the faulty instrument removes the spring from the points on which it rests, and completes the circuit through the battery, so that signals can be *sent*; but in order to *receive*, the circuit must be re-established at the points. The dirt prevents this. A case has occurred in which communication was restored by burning up this dirt by a powerful current sent on the line from another station.

(5.) Signals are uncertain: they sometimes miss. A battery plate is defective, or a connection is loose, and the jar, caused by moving the key, breaks the circuit: the battery-pins, or the springs or blocks on which they rub, are dirty or rusty. When one side of the battery-pin is dirty, and the other clean, the needle can only be moved one way. *Bad oil frequently causes this class of faults.*

(6.) Signals can be sent only when the handle is moved very gently, and when sent fail if a little extra pressure is applied. The cause is a defective connection, which is broken by the extra pressure.

The fault is readily found by holding the handle in such a manner as to cause the signals to fail—that is, so as to break the circuit—and connecting the points of contact, one by one, by a knife or a bent wire, until a part is found on touching which the needle moves, showing that the fault has been bridged over.

(7.) The needle sticks to the ivory pins. Wipe them carefully with a dry handkerchief, or rub the edge of the needle with a black-lead pencil. The needle is not free to move in

the coils, or the pivots are too tight or bent; examine them, and make the necessary adjustments.

(8.) The needle moves in an opposite direction to that of the handle of the instrument. The batteries may be reversed; the needle reversed by lightning; or the coil wires crossed.

Examine the battery wires and the coils; see if the N. pole of a magnet repels the lower end of the needle, as it ought to do.

(9.) Sometimes, in instruments fitted with the handle key, one of the spiral springs which secures the connection of the battery with the barrel is bent, so that, when the handle is moved, it connects one pole of the battery to the line or earth, and thus puts it on short circuit.

(10.) Levers or handles stiff in their bearings causing occasional disconnection.

If the interruption ceases when one particular station works, call that station if possible; if not, call every station you can, and ask each to look at his handle or key. Too great care cannot be taken to make the keys work freely, and to prevent wear by careful oiling with *best salad oil*. When the barrel of the handle-key has two bearings, the handles are very apt to become stiff from the warping of the wood.

(11.) Wire broken inside percha, especially when the instrument is not screwed down.

(12.) Wires connected, when two or more are fixed down by the same staple, which cuts through the percha.

(13.) Coils fused by lightning, or coil wire broken. In this case the needle will not move on short circuit, or when the line terminals are connected by a wire; even after it has been re-magnetised.

If there are no spare coils to replace those which are damaged, the following temporary expedients may be adopted:—If one half the coil is defective, remove it, and connect the terminal to which its wire was fixed to the bar on which the coils slide, leaving the remaining half in circuit. If both halves are useless, take one-half of the other pair of coils, completing the circuit, as in the former case, by connecting the terminals left vacant to their respective frames. The signals will be weak,

but readable. If both sets are damaged, connect the coil terminals across, so as to enable the rest of the circuit to be used.

(14.) Cross movement of the needles of a double needle instrument. Although this form of needle instrument has almost become extinct, it may be well to retain the following paragraph, inasmuch as it may be useful in showing the course of the current when two wires touch, and therefore help in tracing a contact between two lines of single needle instruments.

When the wires of a double needle circuit are in contact, if one of the handles of an instrument is moved, it will make the needles of the sending instrument converge, and move both needles of the other stations, making them either convergent or parallel.

Suppose the left handle is moved to the left, as if to make E, the current will divide at the point of contact among all the channels open to it; part will continue along the wire on which it was sent, part will pass into the second wire, and flow along it to the earth at each end, travelling back through the sending station to earth, and through the stations beyond the fault to earth. The current in the second wire will travel in the *same direction* as in the first to the earth beyond the fault, and in a *reverse direction* to the earth on the same side as the sending station. Thus the needles of all stations on the same side of the fault as the sending station, will converge; and those beyond the fault move in *parallel* directions.

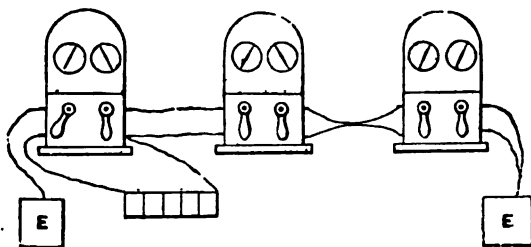


FIG. 101.

By calling the several stations, and getting them to move their needles, left right, left right, you may find with certainty between which stations the fault lies. Call the middle one: if

your own needles converge, the fault is beyond that station. Call the other stations beyond in succession until you find one which causes your needles to move parallel. This station is on the opposite side of the fault to those which cause convergent movements.

There is but one exception : when every station gives Z Q Z Q for + E H N, that is, cause your needles to converge, the earth is defective at one of the terminal stations.

376. The signals of the needle-instrument are movements of the needle to the right or left. They are now so arranged that the *dash* of the Morse alphabet shall be represented by a movement to the *right*, the *dot* by a movement to the *left*.

The movements of the needles are limited by stops fixed in the dial plate ; the instrument is, in fact, a galvanometer with a reversing key. The inner needle, that which is placed inside the coil, is about an inch in length, the north pole downward ; care is required in balancing it that it may not rebound from the limiting stops, or vibrate too quickly so as to confuse the signals.

The coils are wound with wire of 8 mils, to a resistance of about 200 ohms.

377. The use of the needle-instrument is confined to England, yet its advantages for circuits of moderate traffic merit a wider use. It is less liable to get out of order than any other form of telegraph ; there are no adjustments, so that no skill whatever is required in its management ; and its signals are legible until the current itself fails.

ACOUSTIC TELEGRAPHS.

378. The visual signals of the needle-instrument may be replaced by audible signals from two bells, or flat metallic plates of different tone, struck by hammers fixed to the armatures of two electro-magnets ; one of which is arranged to be moved by the positive, the other by the negative current. The key is the same as that of the needle-instrument.

The current from the line is seldom sufficiently powerful to produce a distinctly audible sound, so that a relay with two magnetized armatures, or a double relay is required, adjusted by springs, the tension of which must be regulated to suit the strength of the current. Much more intelligence is, therefore, required in the clerk than in the case of a needle-instrument.

379. The *Sounder* (Fig. 102) is one-half a bell-instrument, or the Morse electro-magnet and lever without the wheelwork. The

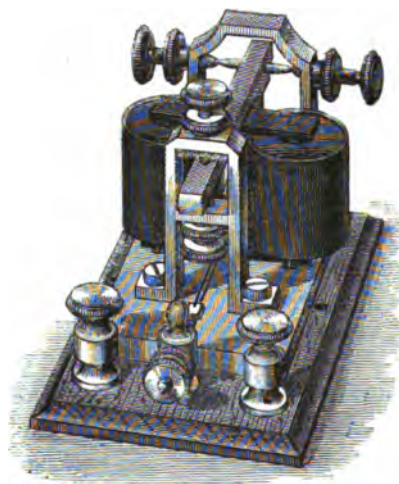


FIG. 102.

signals are the dash and dot of the Morse alphabet, in fact, the signals of the Morse apparatus itself can be read by the sound of the armature. The adjustments required are but one-half those of the bell, consequently less skill is required in the manipulator; moreover, the so-called "double current" system can be applied to the sounder, but cannot be applied to the bell, so that the electrical difficulties are much less.

380. It is true that in skilled hands a higher speed may be attained with the bell, because its signals are all, as it were, *dots*; while those of the sounder are dots and dashes, the dash requiring thrice the time of the dot. Yet the signals of the

sounder can be read as fast, if not faster, than they can be transcribed ; and, moreover, because of its greater simplicity of adjustment, and its lesser liability to disturbance, from the varying state of the insulation of the line-wire, much less time is lost from illegible signals than is the case with the bell. The sounder will, in fact, work well where the bell fails. Hence the bell is rapidly falling into disuse ; indeed, it has never been employed but in this country. The sounder is, with very insignificant exceptions, the only telegraph used in the United States, and in India. Its use is daily extending in England.

Like the bell, it generally requires a relay ; for the current from the line is seldom sufficiently steady in strength to admit of an easy adjustment of the instrument, seeing that some force is required in the blow of the armature to produce a clearly audible sound.

The sound is sometimes increased by placing the apparatus on a sounding-board, but in America, after having tried many experiments, sounding-boards have been abandoned, the instrument being simply screwed down tightly to the table.

The key for the sounder (Fig. 102) is the same as that used for the Morse recorder described in the next section.

The great advantage of the bell and sounder over the needle is, that the clerk writes, as it were, from the dictation of his instrument, and confused signals are more readily deciphered by the ear than by the eye, just as indistinct speaking is more readily understood than indistinct writing.

RECORDING TELEGRAPHS.

381. A *recording telegraph* writes its own signals upon paper, either in ordinary letters, or in a special alphabet of dots and dashes, or of dots arranged in parallel lines, so that the signals of the bell and the sounder can be registered on paper.

The alphabet in most general use is the "*Morse*," composed of dots and dashes ; with the exception of the United States, whose

alphabet differs in a few letters, the same characters are employed throughout the world.

382. THE BAIN SYSTEM.—In this telegraph the Morse signals are produced by chemical decomposition. When a current is caused to pass through the solution of a chemical compound, it decomposes it or separates its component parts; in many cases producing an alteration in colour, either by causing the wire which conveys the current to be dissolved, or by separating a coloured solid substance from a solution previously colourless. Thus if a current be made to pass through paper soaked in iodide of potassium, mixed with starch, iodine will be separated at the wire connected to the copper of the battery, and a brown stain will be produced.

383. It is more convenient to employ a mixture of equal parts of saturated solutions of ferrocyanide of potassium and nitrate of ammonia, diluted with an equal volume of water—one part of each solution to two parts of water.

Place a sufficient quantity of good nitric acid in a wide pan of glass or stoneware, and throw into it lumps of ordinary carbonate of ammonia until it ceases to effervesce, taking care not to put in so much at once as will render the effervescence violent, and that enough is added to leave a small portion undissolved after the acid is saturated, for it is necessary to have a little free ammonia (*i.e.* ammonia not combined with nitric acid) in the liquid. This liquid will be a saturated solution of nitrate of ammonia, with free carbonate of ammonia.¹

The saturated solution of ferrocyanide of potassium is made by dissolving as much of that substance as the water will take up.

It is better to mix only as much as will last two or three days, for *mixed* solution decomposes. The prepared paper should be preserved in a covered jar, in order that it may not become dry; and it must not be used too moist; it should always be prepared five or six hours before it is wanted for use.

¹ The following formula has also been given. To each pint of a perfectly neutral and saturated solution of nitrate of ammonia, add one dram of carbonate of potass.

Nitrate of lime can be used instead of nitrate of ammonia ; it is made in a similar way, and is very much cheaper, but does not answer quite as well.

The principle of the invention may be elegantly shown in the following manner:—Soak a sheet of printing paper in the mixed solution, blot it off, and lay it smoothly on a plate of zinc or sheet of tinfoil connected with the zinc of a Daniell battery of twenty cells. Connect a steel pen, fixed in a wooden holder, with the copper of the battery by means of a flexible copper wire. The pen will now be found capable of writing in blue upon the prepared paper ; but if either wire be disconnected from the battery the pen will cease to mark, the power to do so being entirely dependent upon the passage of the current.

384. In Bain's telegraph, a ribbon of moistened paper is carried forward by clockwork over a metallic roller, thus—

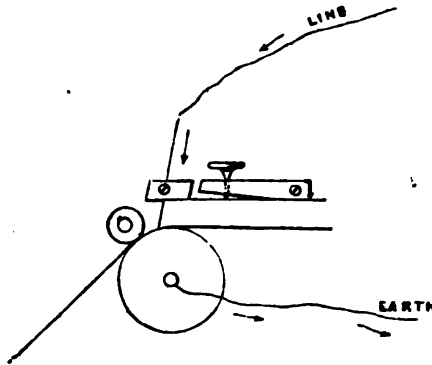


FIG. 103.

and is made to pass under a pencil of iron wire, connected to the line wire, or to a relay, in such a manner that the positive or copper current passes *from the wire to the paper*, and through the paper to the metallic wheel of the apparatus which moves it forward.

When a current is sent on the wire, the solution with which the paper is soaked is decomposed, combining with the iron pencil to form Prussian blue, and making a blue mark on the paper.

On short lines the *line current* (current from the sending station) is sufficiently powerful to decompose this solution, but on long lines it is necessary to employ a local current from a relay. The local battery should consist of 18 or 24 cells of an ordinary line battery. Iodide of potassium and starch is easily decomposed by the line current, but the writing speedily fades away.

Care must be taken to keep the wheel over which the paper runs quite clean, or the current will not pass freely.

385. All pieces of metal exposed to the action of the paper or solution should be tinned, as the liquid has no action on tin, while it rapidly dissolves copper or brass. A little dilute ammonia readily dissolves the compound of copper which is formed.

386. The Bain apparatus is very useful for experimental purposes, as two or more separately insulated pencils may be placed side by side upon the ribbon. It may be used as a chronograph for ascertaining the speed of transmission of signals, by connecting one pencil with the pendulum of a clock beating seconds, so as to mark a dot upon the ribbon each second; and another pencil with the line wire. The signals will then be registered parallel with a scale of seconds, so that the time occupied by each and the number received in a given period can readily be ascertained. The speed of the machine will be sufficiently uniform during each second.

When it would be inconvenient that the marking pen should dissolve away, platinum wire is used instead of iron, and the paper is prepared with a solution of nitrate of manganese.

387. THE MORSE RECORDER consists of a key for sending the current, and an electro-magnet, the armature of which is fixed to a lever carrying a point or style, which embosses a mark upon a band of paper carried forward by wheelwork. The electro-magnet attracts its armature as long as a current is made to flow through the wire with which it is wound, and ceases to attract it as soon as the current is cut off by breaking battery contact with the key; the armature is then brought back by a spring. The paper is carried forward by two rollers, in the uppermost of which there is a groove to receive the point of the style.

388. Digney's *ink-writer*, as manufactured by Siemens, is a great improvement upon the original Morse instrument, and has superseded it. A small thin disc is fixed upon the armature lever, and is driven by the clockwork in a direction contrary to that of the paper ribbon. The disc dips into a trough filled with an ink made by diluting good printer's ink with olive oil, from which the stearine has been removed by freezing; and when raised into contact with the paper, by the action of the electro-magnet, writes the signs in colour upon it. The embossed marks can only be read in a certain light; the written signs are as legible as can be desired; the apparatus is capable of being worked by a much feebler current, and requires but little more care, than the Morse.

The duration of the current and length of the mark in both instruments depend upon the duration of the contact made by the *sending-key*. This key is the same as that used for the sounder.

389. There are three systems of Morse signalling: the constant-current or closed-circuit, the single-current, and the double-current system. The first is universal in the United States, the second almost universal on the Continent, the third is peculiar to England.

390. *Closed-current system*.—Under the European system there are batteries at every station, and the line circuit is not connected with the batteries except at the moment signals are passing. Under the American system the batteries are permanently connected with the line and the sending keys at the several stations are so arranged that when they are at rest a constant current flows through the whole of the instruments, attracting their armatures; so that, if the paper were allowed to run forward, a continuous line would be marked upon it. By opening a switch attached to the keys the circuit is broken, and the break or gap thus made can be again filled up by pressing the key. Thus, if any station opens its switch, the current ceases, and all the armatures are released; if this same station presses its key, the circuit is again closed, and the armatures are attracted so as to produce signals.

The best position for the batteries is one-half at each terminal

station ; for if they are all placed at one station a fault on the line will obviously have a greater effect upon the working of the circuit than when they are divided.

Fig. 104 is the most approved form of the American Morse key for the closed circuit system. The lever is connected to line through the receiving apparatus, and when at rest its right-

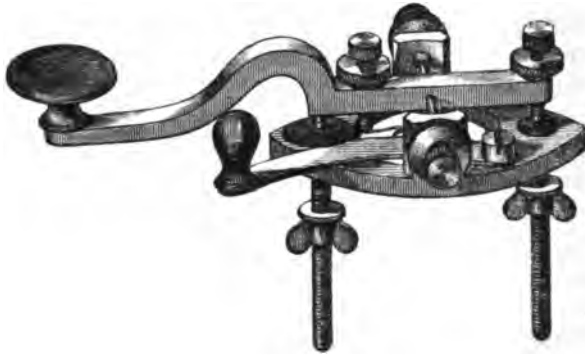


FIG. 104.

hand end touches the stud below it, which is insulated from the frame and connected to earth.

When pressed, the key breaks contact with this stud, and touches that on the left of the frame. This is also insulated, but can be connected to the frame by closing the switch shown at the front of the cut. The stud itself is connected to the sending battery, and the other pole of this battery is to earth.

Except during the act of sending signals, the battery stud is connected through the frame and key to line by means of the switch, so that a constant current passes out to line, attracting the armatures of all the instruments in circuit ; but when about to signal, the switch is opened, so as to disconnect the battery from the line and release the armatures. When the key is pressed, it again connects the line with the battery, and a signal is sent.

391. There are several objections to the system of constant currents. It rapidly destroys buried wires, if they are at all

defective in insulation; and the fluctuation of the strength of the signals is greater than under the other system. Many badly insulated lines, worked with difficulty as closed circuits, have become much more trustworthy when connected up as open circuits. The system has been abandoned at home, except in special cases, notwithstanding its great convenience with respect to batteries. The open or European system is far less costly, as regards battery power, than the American or closed circuit system, the latter employing powerful and costly Grove batteries, the former comparatively feeble and inexpensive Daniells.

392. *Single-current system*.—If the switch is removed, the key becomes the ordinary *single-current* key of the European system (Fig. 104). Batteries are placed at every station; they are connected to the left-hand stud of the key and earth as before, the line wire direct to the lever, and the right-hand stud to earth through the receiving apparatus, so that *outgoing* signals do not pass through it.

393. For distances not much exceeding 100 miles, an ink-writer, wound with wire eight mils diameter, to a resistance between 450 and 500 ohms, may be satisfactorily used on a circuit having no intermediate instruments.

Where there are several instruments in circuit, or where the circuit much exceeds 100 miles, the adjustment for current becomes difficult, as it is hardly possible to arrange that the strength of the signals from each station shall be uniform, and it is better to use a relay (404), which requires but a very feeble current, and is much more easily adjusted.

394. Adjustment is necessary for the following reasons :—

The attraction of the electro-magnet for the armature decreases very rapidly as the distance between them increases; therefore, the weaker the current the nearer must the armature be allowed to remain to the magnet when at rest. This adjustment is made by the screw which limits the distance between the magnet and the armature. The spring which draws the armature from the magnet provides a second adjustment to suit the varying strength of the current.

*Notes as to the Adjustment of the Ink-writer when worked by
Line Current.*

395. (a) First adjust the screw which limits the approach of the armature to the electro-magnet, so that the upper edge of the inking disc shall gently touch the paper when the armature is attracted, while the lower part of the disc dips into the ink. If the disc presses the paper too hard, it makes thick and indistinct signals: if it presses too light, it causes the disc to jump and signals to split: thus — may become - - or - - -.

(b) Raise the electro-magnet by its adjusting screw, so that when the armature is attracted only a thin streak of light can be seen between the electro-magnet and the armature.

(c) Adjust the screw which limits the upward motion of the armature so that it may be free to move through a space of about a sixteenth of an inch.

(d) Adjust the tension of the spiral spring which acts in opposition to the force of the current, so as to bring back the armature to its position of rest when the current ceases to act, and to overcome the effects of *residual magnetism*, if any exist. The amount of tension required will vary with each instrument. The letter V generally should be sent by the distant station using very low power, and the spring gently tightened until the marks are clear and distinct. The ear is usually the best judge of this adjustment.

The instrument is now regulated to work with the most delicate currents.

(e) The adjustment for the stronger current of a nearer station is made by lowering the electro-magnet, and, if absolutely necessary, tightening the spring.

Notes as to the Management of the Embossing Morse.

396. Whatever tends to make the running of the paper irregular is apt to shorten dashes into dots, or to cause dots to be lost altogether. This happens when the style of an embossing

Morse is adjusted so as to mark the paper too deeply, when the paper sticks in the guides from irregularity in width, and when it does not run freely from the drum on which it is held.

If the style is not so adjusted as to move freely in the groove in the upper friction wheel, the signals will fail more or less; and if it is so much on one side as to be completely out of the groove, no marks at all will be produced. These faults generally arise from too much end play in the pivots of the lever, or from the screws working loose. When the lever works too loosely in its bearings, irregular dashes, too deep at their commencement, but tapering off to nothing, are produced; when the armature is first attracted, the style indents the paper, but the forward motion of the band causes the lever to recede in its bearings until the style ceases to mark.

Residuary magnetism (130) frequently causes the armature of the electro-magnet to *stick*, or remain attracted, and can be prevented by occasionally reversing the connections so as to make the current pass in the opposite direction. The armature will always *stick* if it is allowed to touch the core, because the polarity of the iron will not cease when the current is cut off. The screw stop should therefore be adjusted so as to prevent the armature approaching the poles of the electro-magnet too closely, and if the current is so feeble that the armature must be allowed to approach as closely as possible, a piece of writing-paper may be laid over the poles of the electro-magnet, to prevent actual contact.

397. The method of connecting Morse instruments worked by line current is shown by Fig. 105. In this cut, P represents a lightning arrester, made by twisting two wires together.

398. RELAYS.—The *relay* is an apparatus capable of being actuated by a feebler current than that required for a signalling instrument; it is, as it were, an automatic *key* which is set in motion by the line current, which, by closing a circuit composed of the Morse or other signalling instrument and a local battery, causes a stronger current to act on the apparatus than that conveyed by the line wire. Or, in other words, when the current conveyed by the line wire, because of the length of the circuit, or its defective insulation, has become too enfeebled to act

SINGLE-CURRENT MORSE. THREE STATIONS WORKING BY LINE CURRENT.

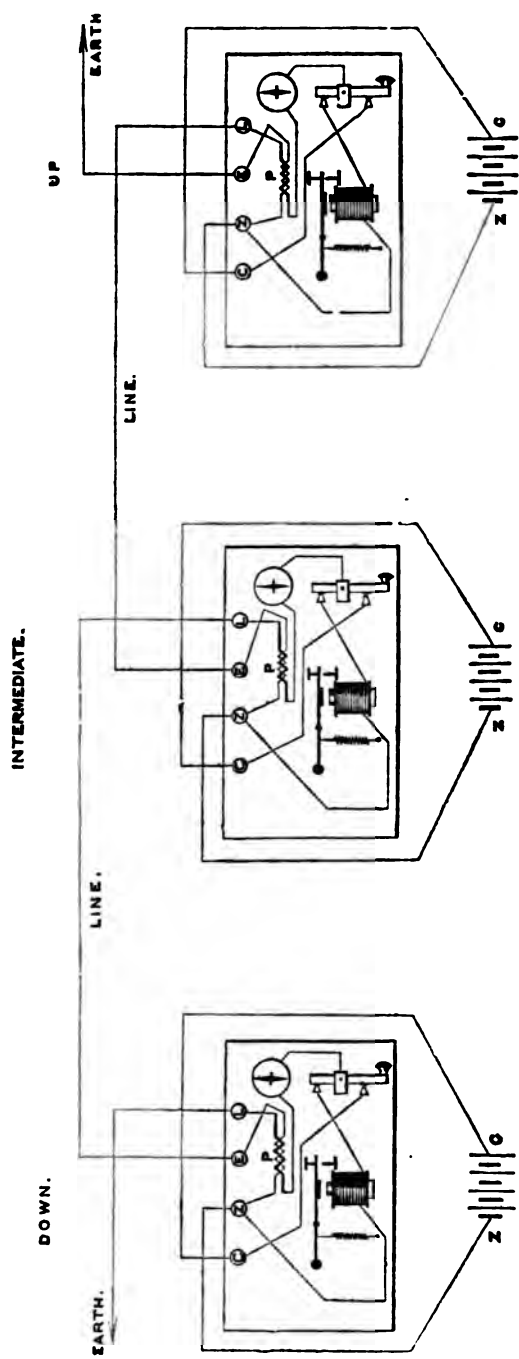


Fig. 106.

directly on the signal apparatus, it is made to act upon a more sensitive apparatus which sets a stronger current in action.

In whatever manner the *relay* may be constructed, its principle is the same. It consists of a bar or armature, either of soft iron or of magnetized steel, fixed so as to be free to move when acted on by an electro-magnet or coil; which, when moved, places a new battery in circuit with the receiving apparatus.

The wire of the electro-magnet or coil (Fig. 106) is placed in the line circuit; the bar is connected with one pole of the

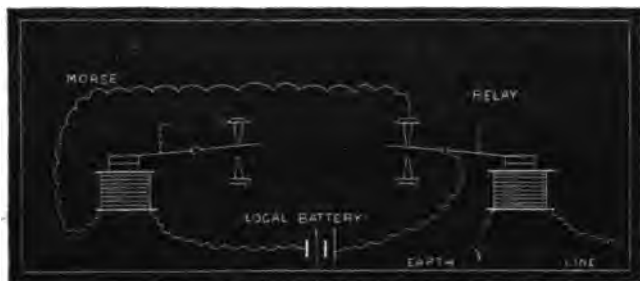


FIG. 106.

local battery; a pin or stop, fixed near the bar, is connected to one end of the coil of the Morse, and the other end of this coil to the other pole of the local battery.

When no current is passing on the line, the bar is held away from contact with the stop connected with the coil by a spring or other means; but when a current is sent on the line, the bar moves towards and touches the stop, so as to *complete a local circuit* composed of the receiving instrument and a battery. Immediately the current ceases in the line wire, the bar flies back, opens the *local circuit*, and rests upon an insulated stop.

These two stops limit the motion of the bar, and their distances from one another and from the electro-magnet are adjusted to suit the varying strength of the line-current (401).

When the line-current is very feeble, the armature must be placed very near the pole of the electro-magnet, and its play limited; when the current is strong its play must be greater.

The electro-magnet itself is sometimes so fixed as to be moved nearer to, or farther from, the armature, so that the effect of the current is increased or diminished without altering the play of the armature between its limiting stops.

The armature must never be allowed to touch the pole of the electro-magnet, as the attraction will then be too great to be overcome by the spring, and the armature will *stick*.

399. *Polarized relays*.—In order to increase the power of permanently magnetized armatures, and to lessen their liability to lose their polarity, they are frequently magnetized by the *induction* of a large magnet placed in contact with or near them. Such relays are said to be *polarized*.

400.—*Siemens' polarized relay* N S (Fig. 107) is a hard steel permanent magnet, whose south end S has a slit, in which the soft iron armature *a* is pivoted, so as to have a free motion from

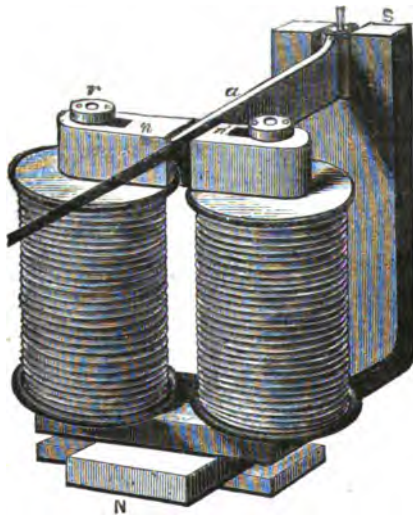


FIG. 107.

right to left. To this armature a thin tongue *b* is attached, which, by making contact at the point *c*, completes the local circuit. To the north end N of the permanent magnet the soft iron cores of the electro-magnet are fixed, as shown in the

sketch. These cores are surrounded with bobbins of wire, through which the current flows. The upper ends of the electro-magnet are fitted with moveable pole-pieces n and n' , which are fixed by screws, as shown in Fig. 107. The permanent magnet $N S$ induces north magnetism in both the extremities n and n' of the electro-magnet, and south magnetism in that portion of the armature which plays between them. When the armature is equidistant from the poles of the electro-magnet, it is equally attracted by each; but if it be brought nearer to one than to the other, it will be held there, because it is under the influence of a more powerfully attracting force. Since the relative distance between the moveable tongue and the two pole-pieces can be increased at will, the attraction between either pole and the moveable tongue can be adjusted with great delicacy without the aid of a spring.

The electrical contacts for the local circuit are shown in Fig. 108, and the diagram is drawn with the tongue breaking the local circuit.

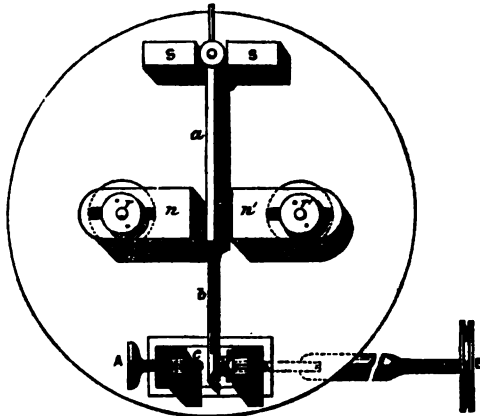


FIG. 108.

401. The adjustments are made thus:—

(a) The pole pieces n and n' are placed at a convenient distance apart, and by the action of the screw B the tongue b is brought, as nearly as possible, in the centre between them (so

as to have equal room for adjustment on both sides). Screw A is then adjusted, so that the motion of the tongue shall be about $\frac{1}{16}$ of an inch between the insulated stud *d* and the contact point *c*.

(b) Screw B is next adjusted, so that when a current is not passing through the coils the armature shall be slightly attracted by the pole, bringing the tongue into contact with the insulated stud *d*.

(c) If, after the instrument is so adjusted, the paper is marked in a continuous line when the distant station is sending, turn screw B to the right, in this way lessening the attraction of *n*, and increasing that of *n'*. If this produces no effect, either place *n* a little farther from, or *n'* a little nearer to, the tongue, until the result desired is attained.

(d) If, on the other hand, there is a loss of dots, turn screw B to the left—thus diminishing the attraction of *n'* and increasing that of *n*. Should this not produce the desired effect, then move *n'* a little farther from, or *n* a little nearer to, the tongue.

The resistance of a Siemens' relay is from 500 to 700 ohms.

402. The polarized relay can be adjusted either to fall back after having made contact, or to remain indifferently in either position. It will, in the latter case, remain where it has been placed by a current, until the arrival of a current in the reverse direction causes it to assume the opposite position, and will therefore produce either dashes or dots at pleasure from key contacts of equal duration; the length of the *mark* will depend upon the interval between the direct and the reverse currents. An important use is made of this principle in the automatic telegraph. With this apparatus Morse signals can be produced by induced currents.

403. The ink-writer is sometimes made with a polarized electro-magnet on the same principle as Siemens' relay, and can then be worked by line current, on the double current system.

When magnetized armatures or bars are used, the line current must be made to pass in one and the same direction through the coils of each relay in the circuit, and the same rules must be observed as in connecting up a series of needle instruments.

But when the armature is soft iron unpolarized (which is seldom the case), it matters not in which direction the current passes through the coils. In the latter case the armature is always attracted, while in the former the direction of its motion depends upon the direction of the current.

404.—In Fig. 109 the larger battery Z C is the line battery; the smaller, marked "local," is the local battery or the battery which is brought into action by the relay 5, 6. The galvanometer 2, 1, is for the purpose of showing whether the current passes; 3, 4, is the single-current key, and the Morse is shown at the left of the key.

The numerals indicate the direction of the current: for instance, if the key at the "up" station is depressed, the positive current of the line battery flows to the key at 3, enters the galvanometer at 2, leaves it at 1, passes along the line to the intermediate instrument, entering its relay at 6, leaving the relay at 5 for the back-stop of the key 4, whence it passes to the lever of the key 3, and then through the galvanometer 2 and 1 to the line leading to the next station.

The numerals serve also to indicate the manner in which the several pieces should be connected. There are two figures on each; the lower of the two is joined to the next lowest, the higher of the two to the next highest, as regards several parts at the same station; and as regards the distant stations, the lowest of each group is connected to the highest of the distant group. Thus 1 of the up station is joined to 6 of the intermediate station.

405. If the coils of the Morse are wound with a somewhat thick wire, as 25 mils, a few cells, say six, will suffice for the "local," but they must be *at least* twice as large as those used for a line battery; if a thinner wire, as 14 mils, be used, ten or twelve cells, similar to those of the line battery, will suffice. The line battery itself, or part of it, may *occasionally* be used as a *local*; but as these cells have very much more work to do than the rest, they become weak sooner, and require constant attention. It is, therefore, much better to use a separate battery, and it is often convenient to use wire of 14 mils for the coil, so that only one description or size of battery is required for the

SINGLE-CURRENT MORSE. THREE STATIONS WORKING BY RELAY.

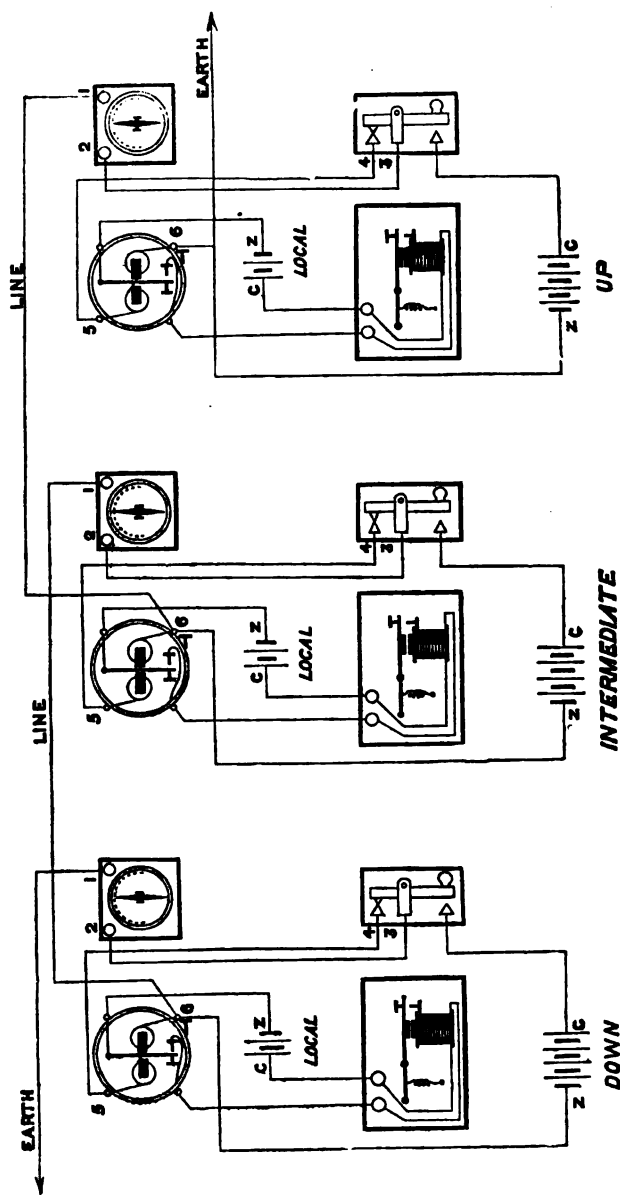


Fig. 109.

work of the office. The coils may have a total resistance of 130 to 150 ohms.

406. Every time a local battery circuit is opened or closed by a relay, a spark passes which burns away the metal at the pivots and other points of contact, and the bar should always be connected to its bearings by a fine wire spiral, or by a drop of best salad oil, which will convey the current and protect the pivot points. When the local batteries are so joined up that the copper is connected to the bar, the oxidation takes place at the pivot, sometimes completely insulating it and breaking continuity. The copper current should, therefore, always be made to flow from the bearings to the pivot, not *vice versa*.

A local battery, if consisting of large cells, frequently causes a relay to stick, by fusing together its points of contact, which must be kept clean and bright by scraping with a knife or very smooth file. Small cells do not fuse metals so rapidly, but, on the other hand, they are more apt to cause oxidation.

The spark, at breaking contact, is much the stronger of the two, because of the *extra current* (181) developed in the wire of the electro-magnet. It may be prevented in two ways. The ends of the Morse coil may be connected by a resistance coil, in the manner of a shunt, through which the extra current will pass, instead of darting through the air. The shorter the wire of this shunt is, compared with its resistance, the greater its effect. It should be made of very fine iron wire, wound half right-handed and half left-handed, so that no induction may take place in the shunt itself, and its resistance should be about 40 times that of the electro-magnet. This arrangement is adopted in Dujardin's type-printer, where a powerful local battery is employed.

Or a small *condenser* (144) of tinfoil may be placed between the terminals of the Morse electro-magnet. The capacity required will vary with the length of the coil and the strength of the battery, but $\frac{1}{2}$ to $\frac{1}{4}$ microfarad will probably suffice.

407. When the current flows in the wrong direction through the relay, so as to complete the local circuit by the *reversed* instead of the *printing* current, signals are reversed, or the spaces between signals printed, instead of the signals themselves, and

the marks on the paper will frequently be dots only. To remedy this fault, the wires of the relay, or the batteries of the sending station, must be reversed.

408. If, when the line current moves the *relay*, the Morse *machine* does not print, the fault will be in the local circuit; arising from dirt on the relay, contact from a broken wire, a loose connection, a faulty cell, or loss of power in the local battery. If the machine does not print when the relay is moved with the finger, the local circuit is certainly defective.

It must be borne in mind that, as the local battery is placed on a circuit of feeble resistance, it will consume much more sulphate of copper than the line battery, and therefore will need greater attention.

409. The longer the circuit on which a relay is placed, the longer and finer should be the wire of the coil; but it is convenient in practice to adopt a coil of average resistance, which will suit all circuits moderately well, because of the difficulty of obtaining proper care in selecting that best suited for each particular circuit. Want of care and defective information are the greatest obstacles to improvement in telegraphy.

410. *Double-current system*.—In the case of an electro-magnet with a soft iron armature, the first effect of reversing the current after the armature has been attracted, is to *repel* it; but immediately afterwards it is *re-attracted*. For, although soft iron loses its magnetism very rapidly, yet it retains it for a short time after the current ceases, so that the armature retains the polarity impressed upon it by the electro-magnet for a moment after the poles of the electro-magnet have been reversed. So long as the armature retains this polarity it is repelled by the reverse current, and if the key by which the signals are sent on the line be arranged so as to give a very short reversal of the current after each signal, a very much less powerful spring will be required to remove the armature, and therefore it will be capable of being attracted by a weaker current. The principle can be well applied to alarums, but is not in this form applicable to signalling. Following out this principle, the most sensitive relay is constructed by abandoning the spring altogether, and trusting to the reversal of the current,

not only for removing the bar from the battery contact, but also for holding it back during the interval between each successive signal. This is effected by the employment of a key, so arranged that, during the transmission of a message, the line is constantly occupied by a current; which moves in one direction to bring the relay into the position of battery contact, and in the opposite direction to remove it from that position and hold it back. The marking current will now have comparatively little work to do, not having to overcome the resistance of a spring; the spring being, in fact, replaced by the reverse or *spacing* current.

The moveable bar or armature must be magnetised, so that the direction of its motion may be reversed by a reversal of the current in a similar manner to the needle of a galvanometer.

411. But another most important advantage is attained by the system, the line is constantly occupied by a current during the transmission of a message.

When the line is free in the interval between signals, as is the case under the single-current system, there is a limit to the delicacy of the relay; because, if very sensitive, it will be acted on by all the small leakages from the other circuits near it, and will print false signals. But when the line is occupied by a current between the signals, there is no such limit, and an instrument, delicate enough to record the leakage from other wires, will yet print accurately whatever is sent on its own proper wire. Should the current leaking into the wire in the intervals between signals be in the same direction as the reversed current, it assists in holding the bar back. Should it be in the direction of the direct or printing current, it will not move the relay unless it is powerful enough to neutralize the reversed current.

412. The principle of the double-current key is readily seen in *Varley's double-current key*, which consists of a divided disc furnished with a lever handle. One half of this disc is connected to the zinc, the other half to the copper pole of the battery. Springs, connected respectively to line and earth, press each upon one-half the disc, so that the battery is always in circuit with the line, during transmission. When the key

is moved, the spring which had previously been in contact with the zinc touches the copper half, and *vice versa*.

This being so, neither station can receive a message until the battery of the distant key is thrown out of circuit. It is, therefore, necessary to arrange the key so that the line-wire shall, during the *sending* a message, be disconnected from the receiving apparatus and connected to the key alone, and *vice versa*. This is effected by means of a switch generally moved by the hand. This switch also disconnects the batteries from the key.

413. An apparent disadvantage arises from this ; the receiving station cannot stop the sender, or reply, until the switch has been turned from *send* to *receive*. The experience of many years has shown that this produces no inconvenience whatever on a recording Morse, nor has it been found a disadvantage even to a Sounder, for repetitions are more conveniently given at the close of a message than during its transmission. If, however, it be desired to give the receiver the power of stopping the sender, a "tell-tale" galvanometer is wound with two separate wires, one of them placed in the receiving circuit, the other between the battery and the key. In sending, the first is switched out of circuit, but the out-going signals pass through the second, and it is also affected by any currents passing inward from line. Thus, it is easily seen if the receiving station breaks the circuit or sends a current. In receiving, the first is placed in circuit.¹

The rubbing contact made by Varley's key is a great advantage when insulation is defective, for the length of the battery contact may be adjusted to suit the state of the line. The worse the insulation, the longer must the current be allowed to flow to line.

But in tolerably well insulated lines it is not necessary thus to prolong the contacts, and as the distance through which the key

¹ Although Sounder apparatus has been provided with this arrangement, it is found that in practice it is never used. This shows that no real disadvantage arises, even on a Sounder circuit, from the inability of the receiver to stop the sender.

must move is found seriously to diminish the speed of signalling, double-current keys are now made whose "play" is as short as that of a single-current key, and their form is constantly undergoing improvement.

414. The single-current key may be made to send double currents by attaching a switch to the *back-stop* (the stud on which the key lies when at rest), arranged to connect it when receiving with the apparatus; or, when sending, with a second battery connected in a reverse direction to the sending battery. When the switch is in the position for *sending*, and the key at rest, a current flows to line, but in an opposite direction to the signalling current. When the key is pressed, contact is *broken* with the opposing battery and *made* with the sending battery.

These switches are frequently made automatic. The armature bar of a relay with a soft iron armature is connected to the *back-stop* of the key. The movement of the bar is limited, in the usual way, by two stops, the first of which is connected to the *reversed* battery, the second to the receiving instrument, and the electro-magnet is placed in the circuit of the *signalling* battery. The armature, not being magnetised, is attracted during the whole time a current is passing from this battery, positive or negative, and the lever is caused to connect the *back-stop* of the key with the reversed battery.

When the key is allowed to remain at rest, the bar is brought by its adjusting spring into contact with the second stop, and the switch is then in the position for receiving from the distant station. It is necessary that this change shall not occur too promptly, or the connection with the reversed battery will be broken before the key touches its *back-stop*, and the reversal will not pass to line. The best method of effecting this retardation is shown in the description of the double-current translator. Many other plans have been used, among them a piston moving in a cylinder filled with oil, having a valve which opens as the piston descends, but closes as it rises; and a vane driven by wheelwork. The shunt is, however, the best method, as the degree of retardation can be regulated with great nicety by varying its resistance.

415. When working with reversals, if the line current is very weak, there is a great advantage in keeping the local circuit always closed by giving the bar of the relay a tendency to rest against the battery contact stop, instead of upon the insulated stop. It requires a certain force to *make* perfect contact, but very much less to *break* contact; thus, when signals are weak the current may have power enough, when reversed, just to remove the bar from the battery stop, so as to *break* contact, when it would not be able to press them sufficiently firmly together to *make* contact unless aided by the bias given to the bar, far less to move it through the space between the stops. *Care must be taken not to leave the batteries thus on short circuit when the instrument is not in use, as it would weaken them seriously.*

416. MODIFICATION OF THE MORSE ALPHABET.—From the date of the introduction of the Morse system; it became apparent that much time and paper ribbon would be saved if the alphabet could be, like that of the bell, constructed of dots only, arranged in two parallel lines; because the dash occupies thrice the time of the dot, and three times the length of ribbon. This was easily effected by a double key and two electromagnets, with polarized armatures or relays, one actuated by the positive, the other by the negative current.

As the single-needle alphabet is formed from the Morse, by representing dashes by a movement to the right, dots by a movement to the left, this double lever recording instrument could be inserted in a single-needle circuit—or, in other words, the single-needle signals could be recorded by it. It could obviously, also, be placed in circuit with a bell. These advantages are palpable, and consequently many attempts have been made to introduce the system.

As it was found there was a difficulty in determining quickly in which of the two lines a series of dots were placed, attempts were made to represent the dash by a line vertical to the paper, thus |, so that the letter V, which in the Morse alphabet is ... —, might be written ... | This removed all difficulty in reading, but the line was not easily produced by the ink-writer, and a double dot was substituted,

the V being written . . . : or . . . ; , which is read with equal facility.

But the same electrical difficulties and multiplication of adjustments, which have caused the bell to be abandoned in favour of the sounder, obtain in this system and have prevented its adoption.

SWITCHES OR COMMUTATORS.

417. These are employed for connecting one circuit to another, for dividing a circuit, or for any purpose where connections have to be altered.

In the *lever switch*, a lever or spring is removed from one stop to another by a pin projecting from a moveable axis, or the pin places the axis itself in connection with the lever or spring.

Thus, suppose it to be required to divide the line A B C at the central station B, so as to enable each half to be worked independently :—

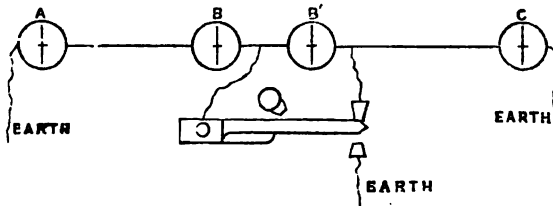


FIG. 110.

(1.) In this position of the switch a signal will pass through the entire line, from A to C, with the exception of the second instrument at B (viz. B'), which, not being necessary, is connected across or placed on *short circuit*. No current will pass through B', because the resistance of its coils is infinitely greater than that of the lever which connects the two ends of the coil wire.

(2.) In Fig. 111, the switch divides the line into two inde-

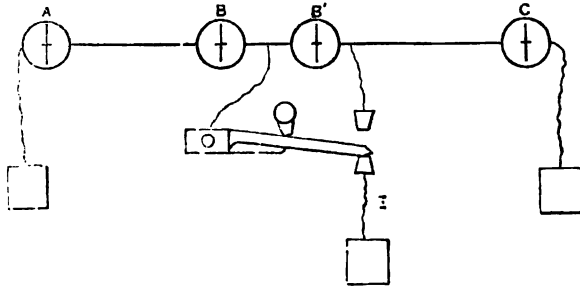


FIG. 111.

pendent portions, by *putting on the earth* between the two instruments B and B'. As B' is now required it is thrown into circuit.

With a *peg switch* the arrangement would be :—

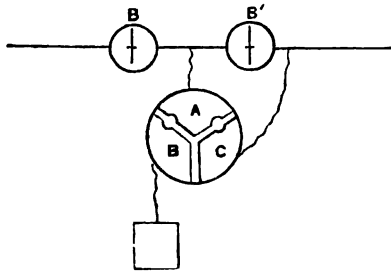


FIG. 112.

(1.) The peg placed between A and C, to work through the whole line.

(2.) The peg placed between A and B, to divide the line into two circuits.

If it be required to connect the line A B either with the line B' C or B' D, or to make the three lines A B, B' C, B' D independent circuits :—

(1.) A through B to C, D and B'' forming a separate circuit.

Place pegs to connect *b* and *c*, *d* and *ed*.

(2.) A through B to D, B and C forming a separate circuit.

Pegs connecting *b* and *d*, *c* and *ec*.

- (3.) Each circuit separate, *i.e.* A to B, C to B', D to B".
 Pegs connecting *b* and E, *c* and *ec*, *d* and *ed*.

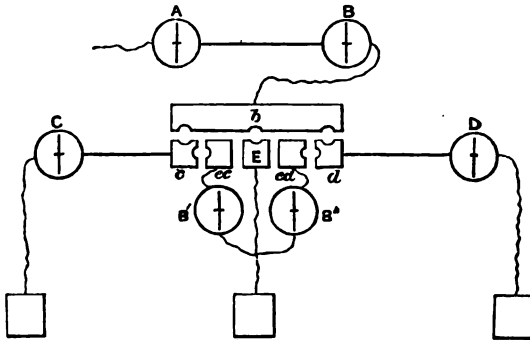


FIG. 113

The same changes may be effected with a switch of three levers.

418. The *Commutator* or *Universal Switch* (Fig. 114) enables us to connect any two circuits.

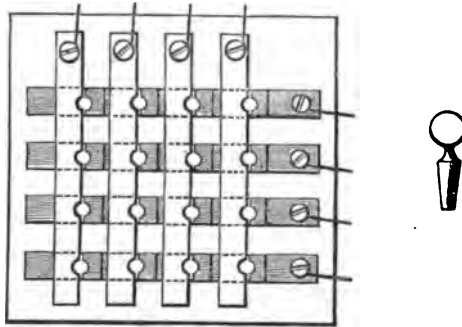


FIG. 114.

Two sets of rods or plates of brass, insulated from one another, are fixed at right angles; holes are drilled through both sets, so that when the peg is placed in any one of the upper holes, it can be passed through the corresponding hole in that bar of the lower set which is directly under it. Thus, any of the upper bars can be connected to any one of the lower.

The peg fits tightly in the upper set of holes, and spring-tight in the lower set. This switch must be carefully kept clean.

The peg switch allows of the greatest number of combinations, and is the cheapest; but the lever switch is more readily manipulated, and is not so liable to be *left wrong* carelessly, so as to disconnect the line. The latter form is especially serviceable when it is required to change several connections at the same time.

419. It is sometimes required to cut an instrument or bell out of circuit.

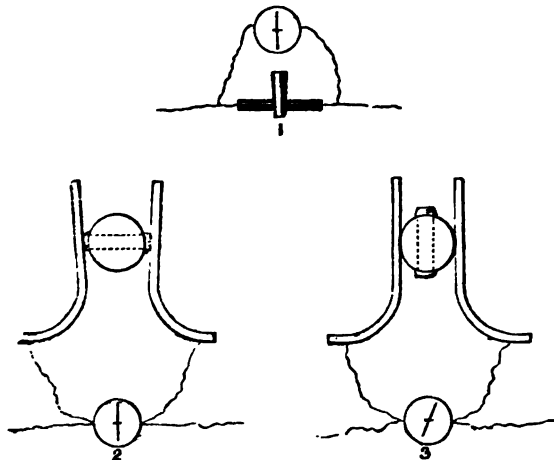


FIG. 115.

No. 1 (Fig. 115) is a peg switch, placed between two brass plates connected with the two ends of the coil wire. Nos. 2 and 3 are different positions of a lever or spring switch, through the moveable axis or *barrel* of which is passed an insulated peg. When the peg is placed in the hole as in No. 1, or when the barrel is turned in the position shown in No. 2, so as to connect the two springs metallically, no current will pass through the galvanometer. If the peg is removed, or the barrel turned into position 3, the short circuit is broken, and the current passes through the coil. A switch of this kind attached to an alarm is called a "*silent*."

TRANSLATORS.

420. When a circuit exceeds a certain length, the line current becomes so much enfeebled, that even if a very large battery is employed at a sending station, signals will not pass. In such cases messages were formerly *transmitted*, that is, read off at an intermediate station and sent on afresh by a second clerk. This duty is now performed automatically by a *translator* or *repeater*. The principle of translation (carrying beyond or forward) is to cause a relay to set in action a key in the same manner in which the key would be actuated by a clerk, and thus send the message forward through a fresh circuit; or, in other words, to complete the circuit between a battery and a second *line wire*, in the same manner as that in which the local circuit is completed between the battery and *the Morse*.

421. Fig. 116 shows the principle, in its simplest form, by which signals may be translated from a distant station B to another at A, on the *single-current* system.

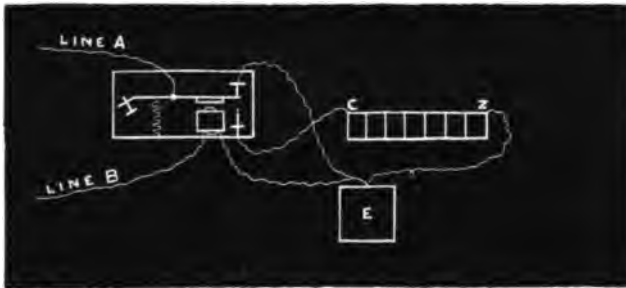


FIG. 116.

Let the two screws which limit the movement of the Morse lever be insulated from each other, and from the lever itself. Let the line wire B, from which the signals are received, be connected through the electro-magnet coils to earth; let the line wire A, to which the signals are to be translated, be connected to the lever; the earth to that screw on which the lever lies when

at rest; one pole of the translating battery to the screw to which the lever is attracted when a signal is being received, and the other pole to the earth.

When no signals are passing from B, the lever puts the wire A to earth. When a signal is received from B, the lever is moved from the screw connected to earth, and is made to touch the stop or screw connected to the battery, so that the line wire A is disconnected from the earth and placed in contact with the battery. The signal received on the Morse through the wire B is thus *sent forward* (translated) to A. By a chain of such arrangements signals may be sent automatically to any distance, or signals may be made to *radiate* from the intermediate office to the several circuits in connection with it, by means of their respective Morse levers.

422. But in order to enable A and B to speak to each other, or to effect translation in *both* directions, or to translate to other lines radiating from the intermediate station, a second translator is required, and a *switch* is necessary to alter the connections when it is desired to work the two lines separately.

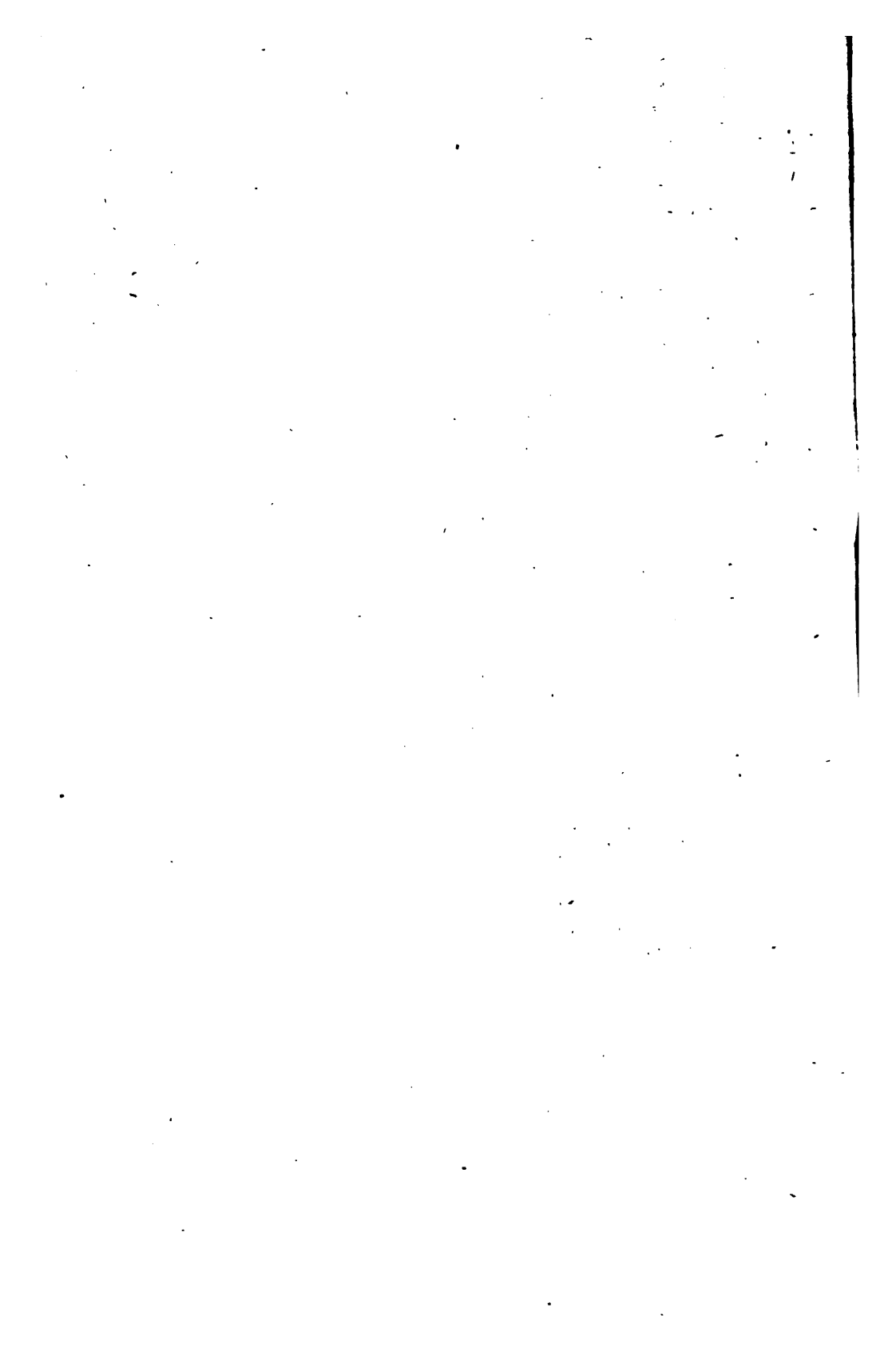
423. SINGLE-CURRENT TRANSLATOR.—The diagram (Fig. 117) shows a system for translating from one line to another, in any direction, from a central station.

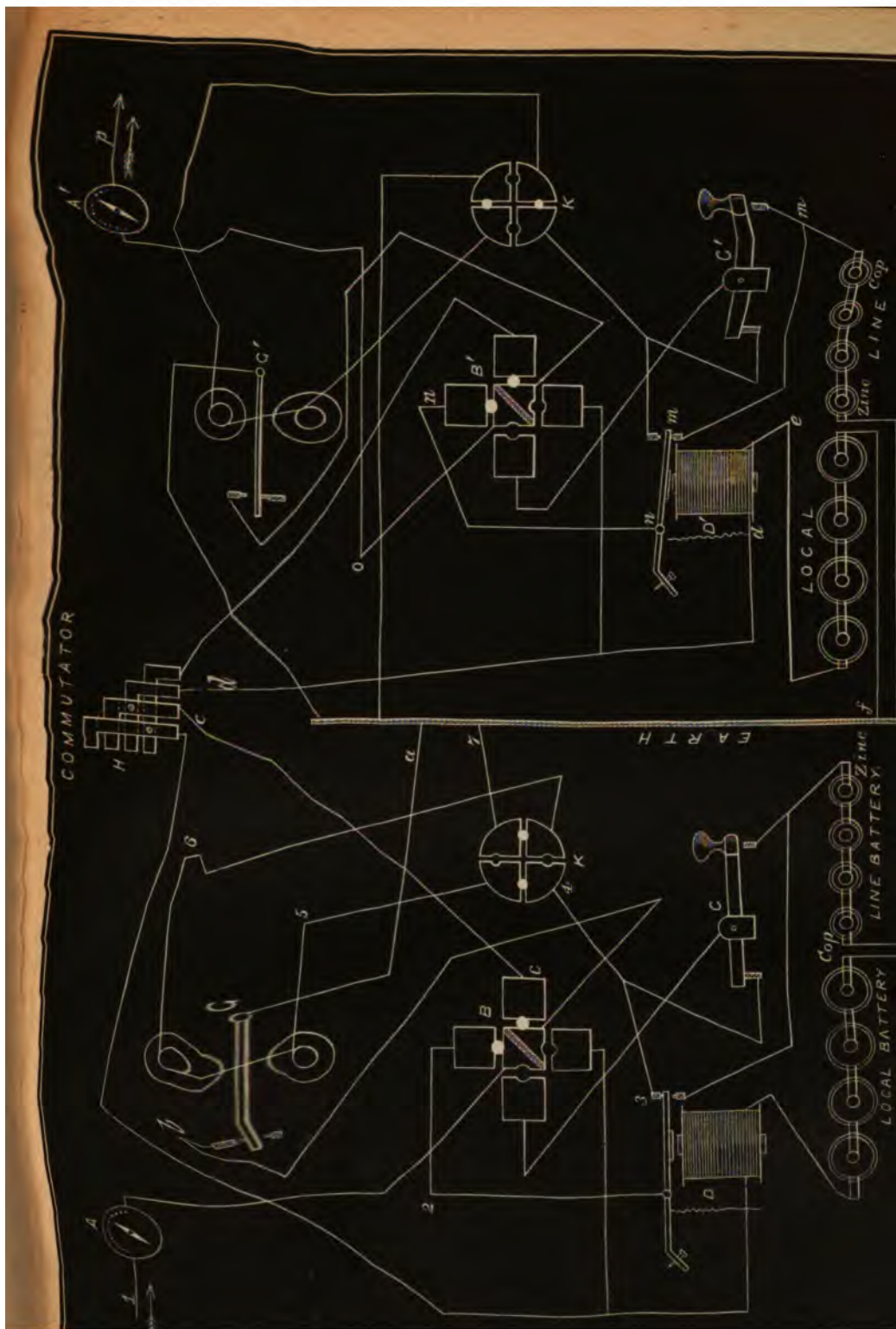
A A' are the galvanometers for showing if the current passes, B B' the small commutators or switches for dividing or connecting the lines, C C' the keys, D D' the Morses, G G' the relays, and K K' the relay switches for changing, when required, the direction in which the line current passes through their coils, H the great commutator for connecting the several lines.

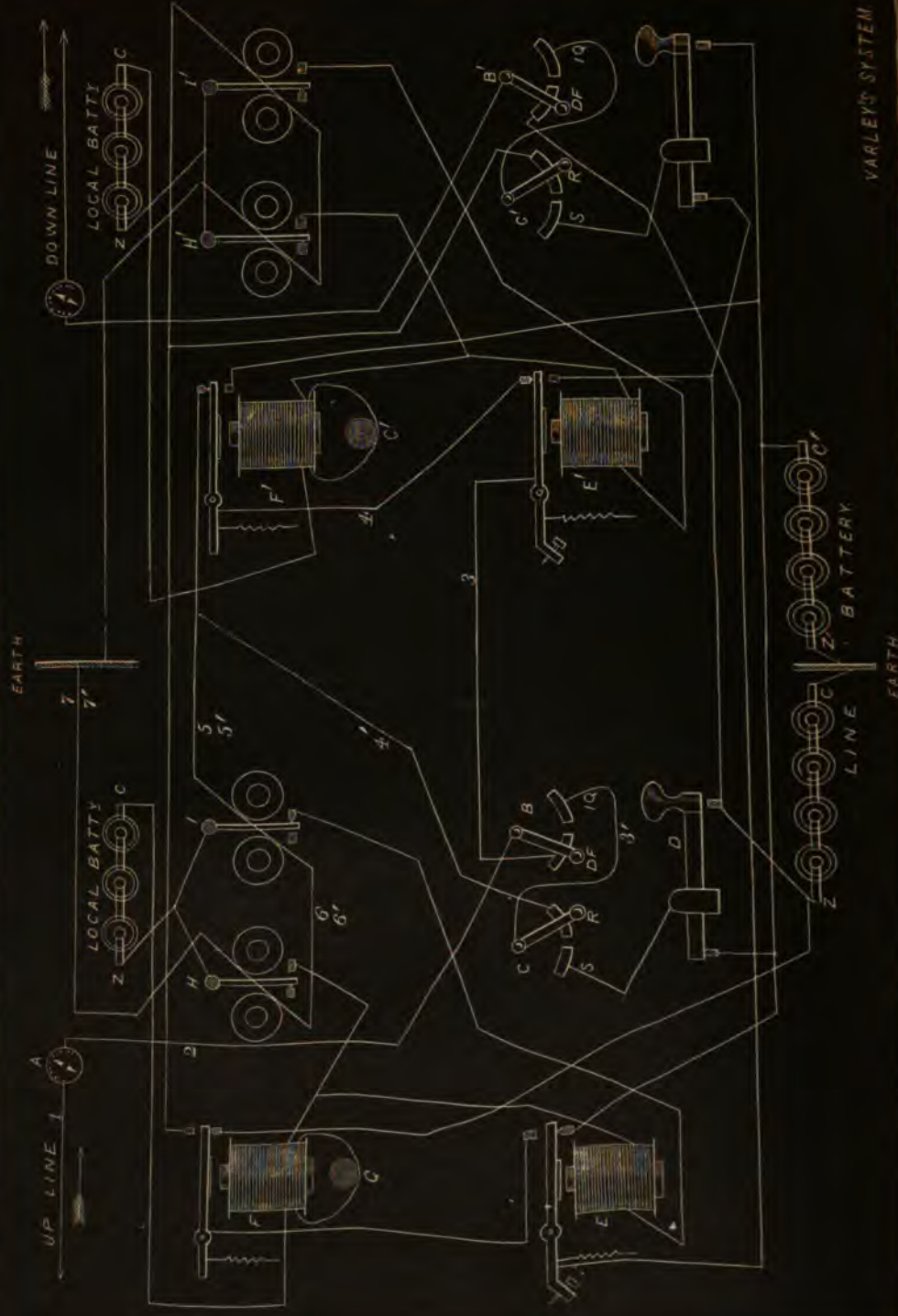
The diagram shows a current in translation from A to A'; the numerals indicate the course of the *received* current, the small letters from *a* to *f* that of the current in the *local* circuit closed by the relay G; and the small letters from *m* to *p* that of the *new* current translated forward by the action of the Morse D'.

To arrange the apparatus for working the circuits independently, the pegs in B and B' are shifted into the unoccupied holes; this places the keys C C' in circuit, disconnects the levers of the Morses D D' and the commutator H, and at the same time puts the Morse coils in circuit with their own relays.









VARLEY'S SYSTEM

No special apparatus, except the switches or commutators, is needed, the translator being composed of the ordinary signalling apparatus. The *great commutator* is a variety of the system of crossbars described at p. 247; every important circuit is connected to it, so that translation can be effected between any two of them.

424. DOUBLE-CURRENT TRANSLATOR.—*Varley's system*.—This apparatus consists of two complete sets of recording instruments, each consisting of a Morse, two relays, an automatic switch, two ordinary switches, a galvanometer, and a key. It is so arranged that the two circuits can either be worked independently, or be connected for translation. In Fig. 118 the apparatus on the left of the earth wire is connected to the up line, that on the right to the down line, and is shown as arranged for *translation*. A is a galvanometer placed in the line wire, B the *line* switch dividing the circuits, so as to be worked separately, or connecting them for translation, I the receiving relay which closes the local circuit containing the Morse E, F the automatic switch for reversing the current, G a shunt for prolonging the duration of the current in the coils of F, H a relay wound in the reverse direction to the relay I, and C the switch of the double-current key.

In this system the line wire is traversed by a current at all times during the passage of a message; which is reversed after each signal, so that it is alternately positive and negative. When the lever B of the line switch is turned to I Q, so as to connect the line wire with the lever C of the key switch, the two circuits are divided, so as to be independent of each other, and the translator is not in action. In sending, this lever C is turned to S (send), and the key is then connected to line, so that each time the key rests on its back-stop a reverse current flows to line from a battery connected to this stop, which is joined up in a reverse direction to the sending battery.

In order to enable the distant station to reply, the line must be disconnected from the key, and connected to the receiving relay. This change is made by turning the switch C from S to R (*send* to *receive*), as has already been explained in treating of the double-current system (p. 242).

To arrange the apparatus for translation, the line switch B is turned from I Q to D F, so as to disconnect the line wires from their respective keys, and connect them to the relays which are to perform the duty of the keys. But the change from *send* to *receive* must still be made, and it is evident that in translation this change cannot be made by hand, but must be effected automatically. It is effected by the automatic switch F, during every slight pause in the signalling, so that one station can stop the other.

Now, in translation, the lever of the Morse takes the place of the key, the key itself having been disconnected by the switch B. The *upper* stop which limits the motion of the Morse lever performs the duty of the *back* stop of the key, and the *lower* stop of the lever the duty of the *battery* stop of the key. The former is connected with the reversing battery in sending, and with the relay in receiving, by the automatic switch F, just as the connections of the key are changed, in hand signalling, by the switch C. It is necessary that this switch be *held in contact* with the lower stop during the whole period signals are being translated, in order that a reverse current may flow to line during the *interval* between each signal; it must also rise during any *pause* in signalling, so as to connect the line with the receiving apparatus, and enable the distant station to reply. It must, therefore, be held down, not only by the marking current, but also by the reversing current received from the distant station, and for an *instant* after, so that a reversing current shall be sent forward by the lever of the Morse when it rises and touches the upper stop, having sufficient duration to act upon the instrument to which the signal is sent forward.

To effect this, the electro-magnet of the automatic switch F is placed in the local circuit containing the Morse E, so that both it and the Morse are acted on by the relay I, and held down by it during the *signal*. It is also placed in a second local circuit closed by the relay H, by which it is held down during the *reversed* current. These relays, H and I, are wound in opposite directions, so that the signalling current moves I, but its effect on H is to press the bar more firmly against the insulated stop, to which no wire is connected. The reversed current, on the other

hand, moves H, but presses I against its insulated stop. I closes a circuit containing F E, and the local battery, and moves both F and E, *while H moves F only*; the lever of the automatic switch F is therefore held down to "send" by both the direct and reverse currents.

But, were there no other force acting on it, the lever would rise the instant the currents ceased, so that the switch would be turned to "receive" before the Morse lever could reach its upper stop. No reversed current would in this case be sent forward to the distant station. It is, however, held down an instant *after* each current ceases, by a special arrangement which allows it to move downwards rapidly *from* its normal position, but delays its rising so that it shall not *have time* to do so until a pause occurs in the signalling.

This effect may be attained by placing a secondary battery (56) in the local circuit of F, so that the polarization caused by the local current which flows through it when the circuit is closed by H shall hold down the lever of F for a second or two; but in practice it is found that as the duration of the current of polarization depends upon that of the local current, it is apt, when the local circuit has been closed for a longer time than usual, to hold the lever down too long.

The required retention can be obtained without this defect by shunting the electro-magnet F by a resistance G about equal to its own, so as to afford a path for the extra current direct (183), which, passing through the magnet coils in the same direction as the battery current, retards its demagnetization. The duration of this retardation may be adjusted, within certain limits, by varying the resistance of the shunt, and the method appears to be free from objection. The power of the electro-magnet is somewhat reduced, but not inconveniently so.

The diagram is arranged to show a signal in translation from the up line to the down, the unmarked figures denoting the successive steps of its path.

The apparatus is drawn as if arranged for translating permanently between *the same* two lines, or for working the two by hand as separate circuits; but if it be required to translate

between *any* two of the lines running into the station, a distinct set is required, which may be connected up to any two lines at the testing box, or by an universal switch.

The marked figures show the steps of a *received* current when the line switch is I Q and the circuits divided so as to be worked by key, independently, the alteration of path commencing at B.

425. Fig. 119 shows another form of double-current translator with double-current keys, instead of single-current keys with reversed batteries connected to the back-stop of the key; and a switch to alter the connection of the line batteries, so as to arrange them either for separate circuits or for translation.

The sounder is used instead of the Morse recorder, so that the attendant may hear what is going on, and be able more easily to watch the apparatus.

The relays are shown at rest, but ready for translation. A current arriving from the up line will follow the course indicated by the numerals 1 to 13; a current from the down line will follow the path marked by the letters from *a* to *k*. The current passes in opposite directions through the switch relay and the sounder relay, so that the armature bar of the one is moved by the +, the other by the - current. But as the coil of the switch is connected directly with the battery, it is acted upon when the circuit is closed by either of the two relays, while the sounder is actuated by its own relay only; thus the *switch* is held down to *send* both by the marking and the spacing (or reversed) current, the *sounder* by the marking current only.

The battery switch connects the batteries either to the keys, or to the automatic switch by which the reversed current is sent.

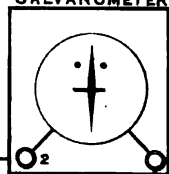
The dotted lines indicate the path of the local battery circuit, which is closed by the relays.

In the diagram the relays are shown at rest, but when a marking current is sent from the "up" station, the marking relay, 9.10, is drawn over, sending a current from the local battery through the translating sounder E and the spacer or switch F, which are held down, E sending a marking current through the galvanometer B to the down line. When the sending station raises his key, he reverses the direction of his cur-

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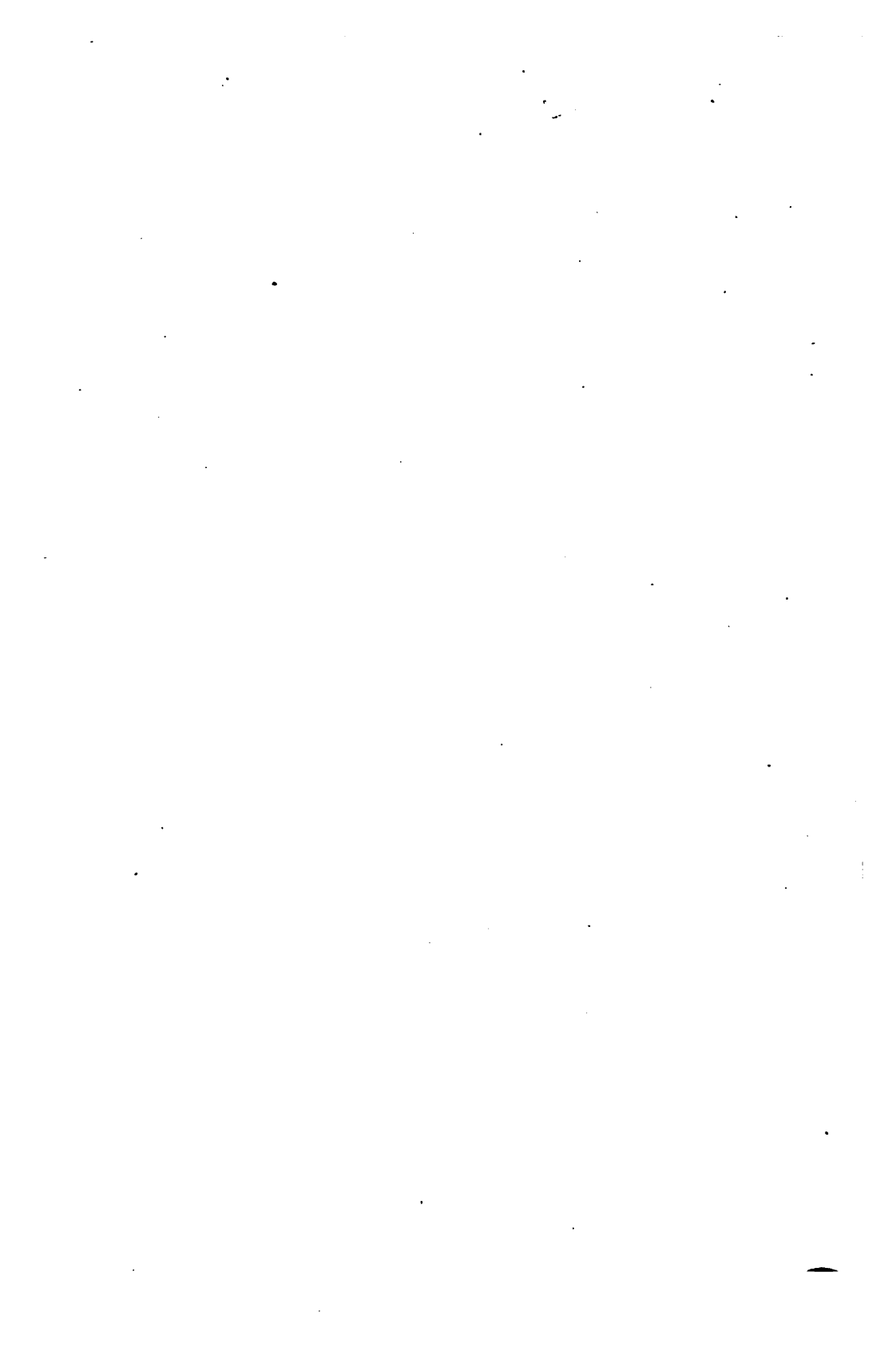
TCH

GALVANOMETER



line, The le





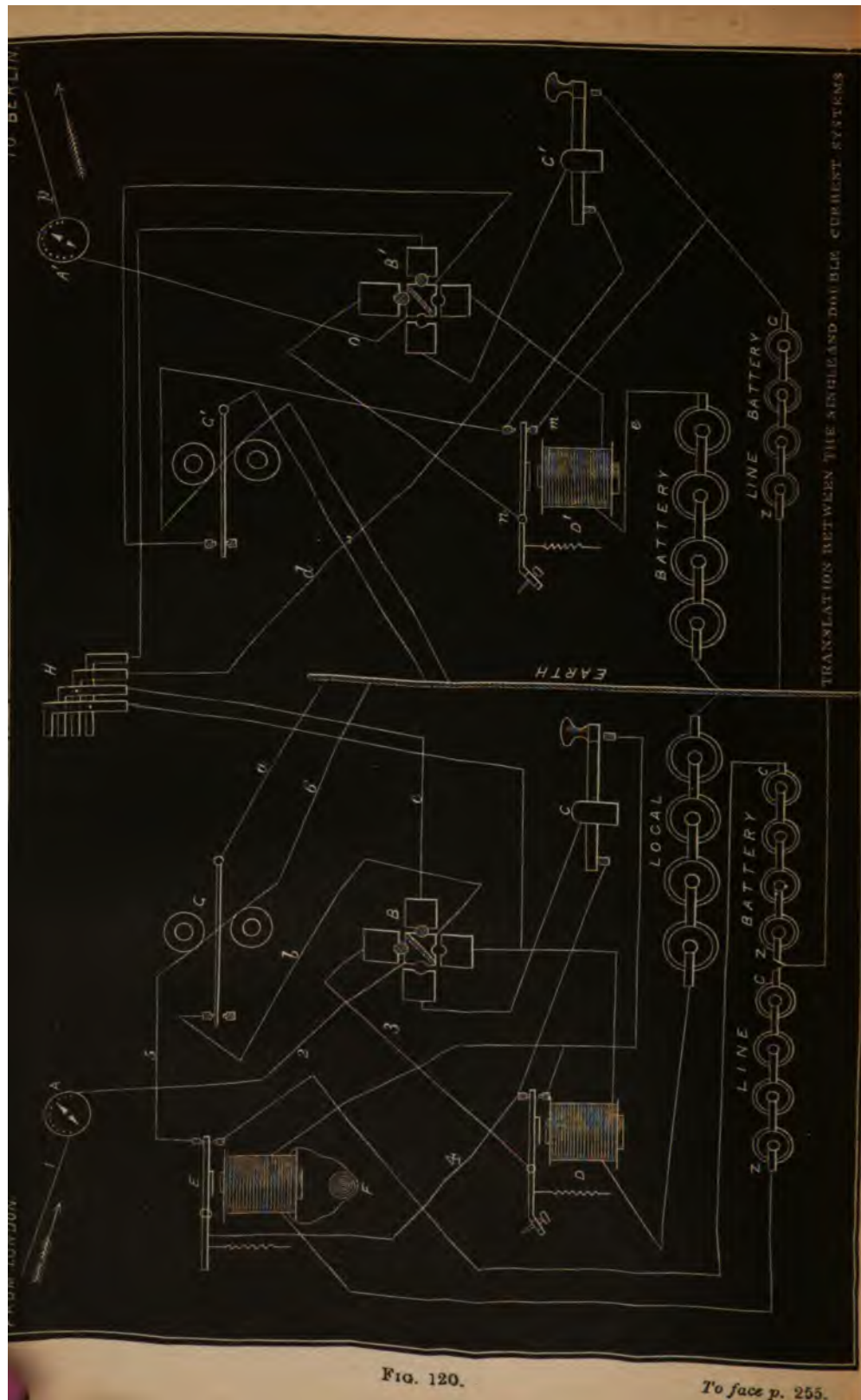
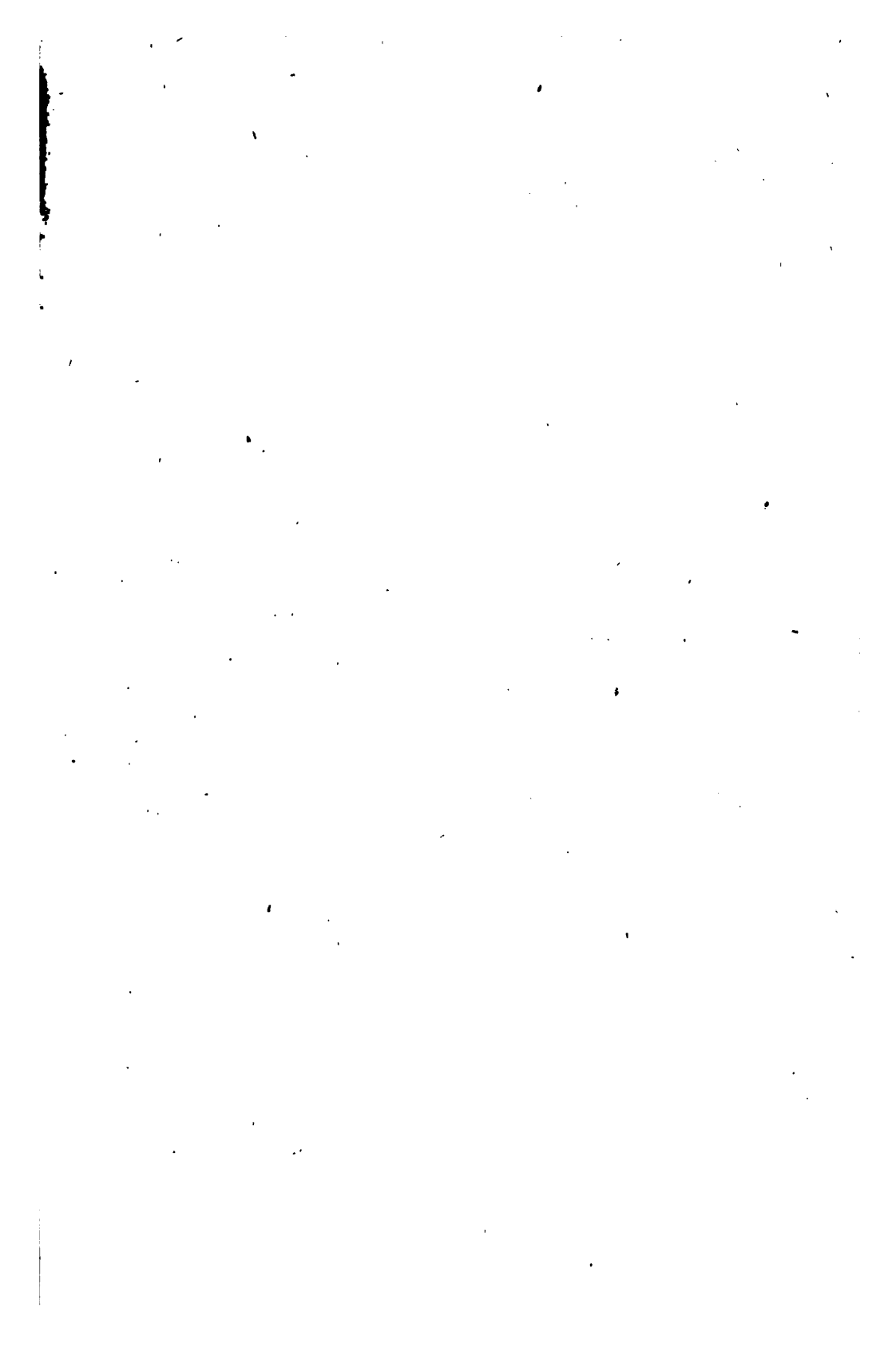
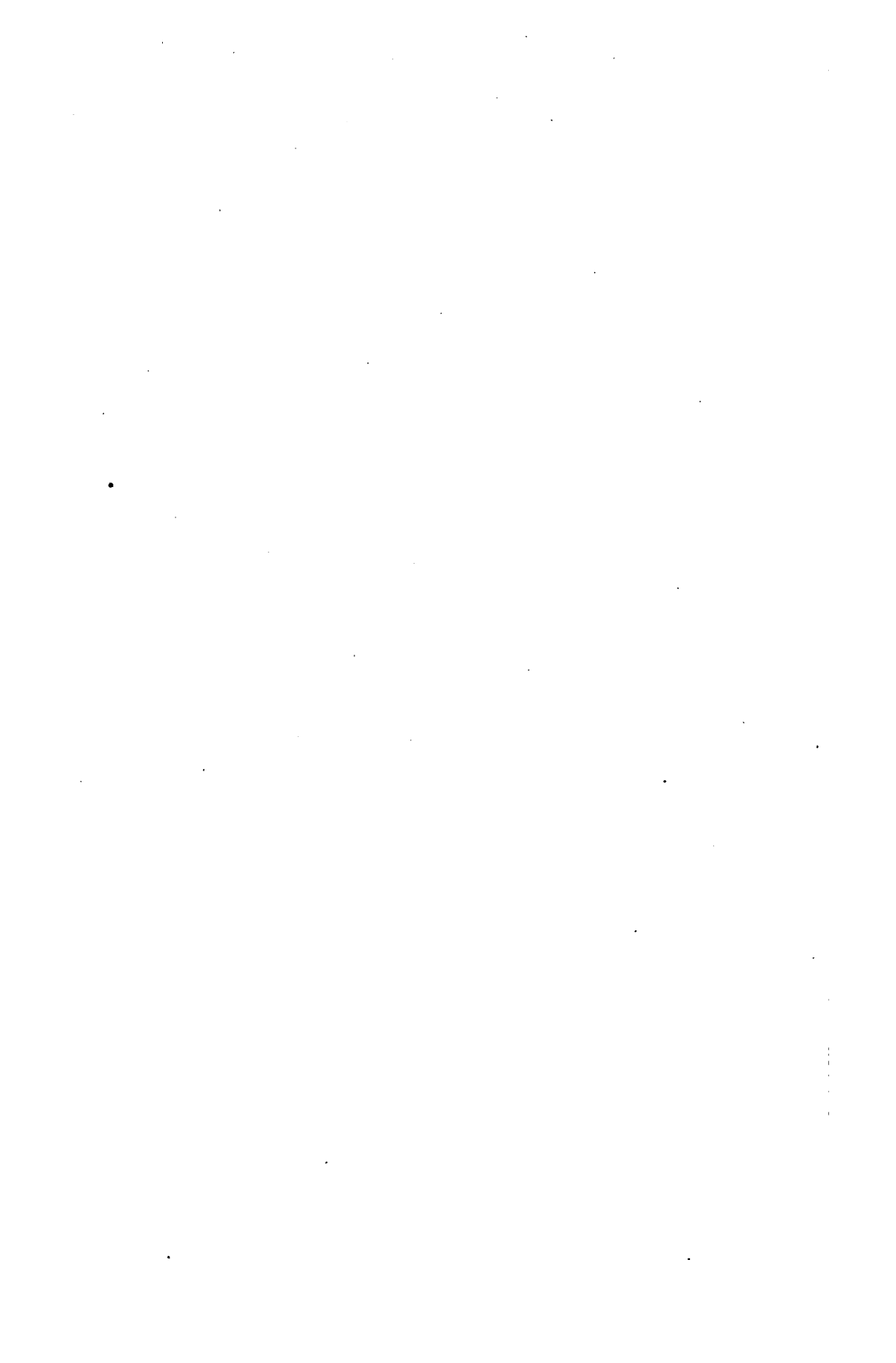


FIG. 120.

To face p. 255.





rent, releasing the relay 9·10, and closing the local circuit through the spacer F only, by means of the relay 11·12: the sounder and the relay 9·10 return to their resting position, but as the spacer is still held down, a reversed or spacing current takes the place of the marking current through the galvanometer to the "down" line.

426. A translator has been arranged for very rapid working, in which the loss of time arising from the space through which the sounder lever has to move is avoided. The current is sent forward not by the sounder, but by a third relay, the sounder being used only for reading. The relay bar may be adjusted so as to move through but a very small space, while the sounder must have considerable play.

In this translator the adjustment of the relays is very important. The relay bar depends solely upon the attraction of the poles of the polarized electro-magnet for regaining its position of rest against the back-stop, as no reverse current passes through it. It must, therefore, be adjusted so as to have a decided tendency to fall back rapidly after each signal, for otherwise the spacing current will not pass out to line.

When this relay is used for translating the signals of the automatic system its action can be tested only by the ear, for its movements are too rapid for the eye to follow, especially with such small play as is necessary to avoid loss of time in relaying the currents.

427. TRANSLATION BETWEEN THE SINGLE AND DOUBLE CURRENT SYSTEMS.—*Varley's method*.—Fig. 120 shows Varley's arrangement for translating between a single-current and a double-current system, as at Amsterdam, where the English system meets the single-current system of the Continent.

The diagram shows a current in translation from London to Berlin. The right side shows the single, the left the double current system.

H is the *great commutator* by which any Continental wire may be connected to any London wire, A and A' are the galvanometers, B and B' the *small commutators* for altering the connections from translation to independent working. C and C' are the keys, D and D' the Mosses, E the automatic switch, F the

shunt for preventing the switch lever rising too quickly, *g* and *g'* the relays for working the Mosses. The numerals show the course of the current received from London, the letters from *a* to *e* the local circuit closed by the relay working the Morse *D'*, and those from *m* to *p* the current sent forward to Berlin. The two sets of apparatus can be worked separately by removing the pegs in *B* and *B'* into the unoccupied holes.

428. It is necessary that translators should be superintended by an efficient clerk who is able to read by sound, so as to hear what is passing and detect immediately when adjustment is necessary. If an embossing instrument is used, the paper band should be removed, in order to allow the lever to move freely.

In cases of apparent inattention to a call, the clerk in charge of a translator should satisfy himself that no fault exists in the apparatus under his care, which would prevent the reply passing his station. This can be ascertained in a measure as soon as the calling station pauses, by closing the line switch on the side from which the reply should be received, thus enabling the reply to find its way direct to the relays without first traversing the levers of the opposite translators, as an oxydized point of contact, or loose connection, would interfere with its passage. The most certain method, however, is to send a current from the testing battery through that portion of the apparatus in which the fault is suspected.

Great care is required with respect to batteries connected to relay apparatus, as they are worked very hard. The most *constant* form should be selected, and exchanged as soon as the plates become thin. About 30 cells for each local, and 70 to 80 for sending sets, in ordinary cases should be sufficient. Weak or defective battery power gives rise to more complaints against the relay than any other fault, and, therefore, must be carefully guarded against by frequent tests, and personal examination of the cells when any doubt exists. Worn plates are often very deceptive, and in testing them the current should be passed through the galvanometer for several minutes, and if any falling off of the deflection can be observed, the set should be at once changed.

It is very necessary that all points of contact be kept bright

and clean. They require more frequent attention in damp weather than in dry, because the moist atmosphere assists the formation of the oxide, which offers great resistance to the passage of the current, and sometimes causes a spark to bridge across the short space between the battery stop and the lever, thus putting a permanent current on both lines, and entirely stopping the working.

The play between the contact points should not be so small as to risk the occurrence of this fault.

The bar of the relays should have sufficient play to break contact with one of the stops before it makes contact with the other. When the relay connected with the automatic switch is not properly adjusted in this respect, the local current, instead of acting upon both the Morse and the switch, will move the switch only, because the battery current finds a short route through the spacer only, instead of through the Morse.

429. As has been said already, particular care must be taken to keep the lever of the automatic switch firmly down while signals are passing, otherwise the marks will be confused, or may appear at the receiving station as a continuous line, owing to the failure of the reversed or spacing current; and when a cable is included in the circuit, should the lever rise during the transmission of signals, it will allow the discharge (or return current) from the cable to find its way to the opposite side of the translator, so as to destroy the signals from the sending station. It must also be seen that the spacer rises when the sending station moves his key-switch to *send*, or a current remains on the line, and the receiving station will be unable to reply.

430. The lever of the translator moves through a certain space before making contact with the battery, so that the duration of the current sent forward is shorter than that received from the distant station. A second translator shortens it still more, so that the dots cease to be translated, or are lost. The sending clerk must therefore key more firmly than usual,

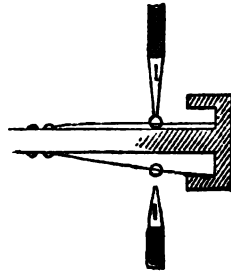


FIG. 121.

increasing the length of his contacts, especially when sending dots; and when insulation is defective, springs may be fixed to the lever of the translator, as shown in Fig. 104, to improve the contacts by giving a slight rub, and to lessen the time lost by the movement of the lever.

In all keys, relays, and other apparatus for sending currents through badly insulated wires, there is a very great advantage in a rubbing contact over a mere blow. When there is a great loss from leakage on the line, it is most advantageous to prolong the contact of the key by a spring, so that a larger quantity of electricity may flow to the line.

LETTER-INDICATING INSTRUMENTS.

431. *The Hughes instrument.*—This apparatus differs from all others in that it is mainly mechanical, the electrical action being confined to the sending a single short current at the instant the type-wheel is in the proper position, and only one wave is needed to produce a letter.

The sending and receiving instruments are precisely alike, and are manipulated by a keyboard of as many keys as there are letters and signs to be printed.

Connected with the keys is a set of *pins* arranged radially in a circular horizontal plane, through the centre of which a vertical shaft passes, driven by clockwork and carrying a horizontal arm called the *chariot*, which sweeps round a little above the pins and without touching them. When a key is pressed, the corresponding pin rises sufficiently high that, when the chariot next passes, it touches it, and sends a current through the instrument coils to line.

The type-wheel is fitted spring-tight upon an axis geared into the shaft which carries the chariot, so that while the two move together, the type-wheel can yet be shifted in position, or even stopped without stopping the wheelwork. If the chariot and

type-wheel are adjusted so that the former shall touch the pin which has been raised by depressing the key, and thus send a current to line at the instant the corresponding letter is opposite the paper; it follows that, if the paper is at this moment lifted into contact with the type, by means of the current, the required letter will be printed.

The speed is regulated by a vibrating spring carrying a weight, and any small error in the position of the type-wheels caused by one instrument running faster or slower than the other, is rectified by the *correcting lever*, which forces a wedge between the teeth of a star-wheel fixed upon the type-wheel, and brings it into position.

The current is made to print the letter in this way:—A hollow shaft carrying three cams is fitted upon the axis of a wheel which gears into that which drives the type-wheel. This hollow shaft is not carried round by the axis which passes through it until the two are locked together by a detent, which is itself put into action by the current passing through the coils of an electro-magnet.

The two then revolve together, and the following actions take place:—

- (1.) The first cam corrects the type-wheel as to position.
- (2.) The second cam presses the paper against the type.
- (3.) The third cam moves the paper forward.
- (4.) The connection between the cam shaft and the axis which passes through it is broken, and the cam shaft comes to rest. A fourth cam replaces the armature upon the electro-magnet, and the apparatus is ready to receive a second current.

The electrical arrangements, though simple, present several specialities.

The electro-magnet consists of two soft iron cores wound with covered wire, and each fitted upon a pole of a permanent magnet. The armature is soft iron, and when placed upon the electro-magnet is retained in position by the polarity induced in the cores by the permanent magnet. A spring, adjusted by a screw, tends to remove the armature.

If a current passes through the coils in such a direction as to develop polarity contrary to that induced by the permanent

magnet, the armature is released, and immediately it has quitted the cores it moves sharply and forcibly under the full force of the spring, and liberates the detent. The armature is replaced by the action of the wheelwork.

The amount of attraction between the cores and armature is regulated by a soft iron keeper which can be placed across the permanent magnet.

This arrangement is exceedingly sensitive. Suppose that the induced magnetism in the cores holds the armature with a force represented by 100, and that the spring opposes a force of 91, a contrary polarity of only 10, produced by the current, will liberate the armature, and when it has once left the cores, it will rise with the whole force of 91; and as it is replaced by the wheelwork, the spring which acts upon it may be set stiffly, for the current has not to overcome it. The instant the armature rises the coils are short circuited, and the received current passes direct to earth. Suppose 100 parts of current arrive, and that five only are required to release the armature, the surplus will pass direct to earth.

When the armature is replaced upon the electro-magnet by the action of the wheelwork, an *extra-current*, in the same direction as the received current, is produced. This acts as if it were a new current caused by the touching of a key and if the resistance of the line be small, it produces a continued to and fro action of the armature, and a succession of letters are printed.

Its formation is prevented by the breaking the circuit of the electro-magnet by the cam shaft immediately it commences to turn, so that at the time the armature is replaced there exists no circuit for the extra-current.

432. The apparatus can be employed as a chronoscope to compare very short intervals of time.

For this purpose the correcting cam is removed, so that the type-wheel is not adjusted at each impression.

If the instrument is on short circuit, and a key is pressed, the corresponding letter will be printed.

But if a long wire is placed in circuit, a certain time will be occupied in the passage of the current, and the release of the

armature will be delayed, so that if key *A* be pressed, the letter *A* will not be printed clearly, or it may be *B* or even *C* may be printed, according to the distance the type-wheel has run during the time the current has been retarded.

Now suppose the type-wheel makes 120 revolutions per minute, or two each second, and there are 28 letters or figures engraved around it. Each sign will pass the printing lever in $\frac{1}{28}$ of a second, and if the retardation be that interval of time, the instrument will print a letter in advance. Again, if the speed of the type-wheel be adjusted to 107.25 revolutions, each letter or sign will pass the printing lever in $\frac{1}{28}$ of a second. If the retardation now be $\frac{1}{28}$ of a second, *B* will be printed for *A*, if $\frac{1}{28}$, *C*, and so on.

433. *The Alphabetical Telegraph* indicates letters upon a circular dial by a hand or pointer. It consists of two parts—the dial, or *indicator*, driven on the step-by-step method by alternating currents from a magneto-electric machine, or *transmitter*.

In Wheatstone's apparatus the transmitter contains a powerful steel compound magnet, having two electro-magnet bobbins attached to each of its poles, the cores of which are magnetized by the induction of the permanent magnet.

A soft-iron armature is fixed on a horizontal axis, driven by a wheel and pinion, so as to revolve in front of the four bobbins and close to the poles of their cores. The passing of the armature decreases for the instant the magnetism of the cores, and develops alternating (or reversed) currents in the coils. Two positive and two negative currents are produced by each revolution of the armature (189).

The armature revolves constantly during the operation of signalling, and produces an uniform series of reversals; and if the right number of reversals be allowed to pass to line, the hand of the indicator will be carried on to the required letter. The number of reversals is regulated by keys.

The indicator consists of a ratchet-wheel driven by a delicate electro-magnetic escapement. Connected with the escapement-wheel is a pointer, which revolves within a circle of letters engraved on the dial; each reversal causes the pointer to advance one letter by a step-by-step movement, and it remains

in its position until an opposite current is sent. Thus, to indicate any particular letter it is only necessary to stop the reversals at the proper time. This is accomplished by the manipulator, or transmitter, which consists of a series of thirty keys, arranged horizontally in a circle, and corresponding respectively to an equal number of letters and signs of punctuation. These keys have vertical pieces attached to and forming part of them, and projecting downwards.

The horizontal axle which carries the armature drives a vertical axle, divided into two parts in the centre of its length. The lower part is driven by bevelled wheels, and drives the upper portion by means of a ratchet and click. The ratchet is fixed to the lower part, the upper part carries an arm, to the extremity of which the click is fixed; the end of this upper axle carries a pointer which shows on a dial the movements of the arm. During each revolution of the lower axle a sufficient number of currents are sent to carry the hand of the indicator once round the dial. So long as the click remains in the teeth of the ratchet the two parts of the axle revolve together, and the reversals pass out to line; but when a key is depressed the piece which projects below it comes in the way of the click, disengages it from the ratchet, stops the upper part of the axle, and breaks the connection between the magneto-machine and the line-wire, and thus prevents the reversals passing to the line-wire at the moment the number required to carry the indicator-hand to the right letter have been sent.

The currents are stopped in this way: a second horizontal arm is fitted spring-tight on the upper part of the vertical axle, so that if the arm were free to revolve it would be carried round by the axle. Its motion is, however, limited by two stops. When the apparatus is at rest, the arm is pressed by a spring against the stop connected to earth; but when the axle turns, the arm is carried by friction from this earth stop to the second stop, which is itself connected to the coils of the magneto-machine. The arm is connected through the indicator of the home instrument to line, and thence to the distant indicator; so that so long as the axle turns the currents pass to line, but when the axle is stopped by the click touching the

depressed key, the spring attached to the arm overcomes the friction of the arm on the axis and switches the line-wire back to earth, stopping the passage of the currents outwards, and placing the apparatus in position for receiving currents from the distant station.

The depression of a second key raises the one first depressed, sets free the revolving arm to move onward until it is again stopped by the second key, when the operations are repeated.

TRANSMISSION BY TWO STATIONS AT THE SAME TIME ON A SINGLE WIRE.

THE AUTOMATIC SYSTEM.

In order that the present Edition may give the latest information respecting these systems, their description is transferred to the APPENDIX.

GENERAL REMARKS AS TO THE MANAGEMENT OF CIRCUITS.

434. *The longer the line, the better the insulation required.*—A very inferior insulator suffices for a short line of but few instruments, but if there be many instruments in circuit the insulation should be improved.

The greater the number of wires, the better should be the insulation.

It is impossible to insulate a long line too well. It must be remembered that an efficient telegraph is one which works well in all states of weather, and consequently the insulation must be adapted to the worst weather, not to the average.

Insulation may be temporarily improved by washing with paraffin oil.

Insulation is more important near the extremities than in the centre of a circuit.

When wires run through districts exposed to excessive rain or to salt spray, so that insulation is well-nigh impossible, a larger wire should be used. In some parts of India an iron rod is used fixed to wood supports, and with advantage; the great conducting power of the rod making up for the deficiency in insulation.

435. When insulation is bad and cannot be improved, the resistance of the battery should be lessened by using large plates, or connecting two or more in series, side by side.

436. On a long line, apparatus having coils of considerable resistance is used in order to multiply the effect of the current; but when there are several stations in the circuit, the apparatus resistance exceeds that of the line, and again demands a battery of higher potential and of greater resistance to overcome it. In fine weather the inconvenience is not felt, because there is then no difficulty in obtaining good signals with even a very small number of cells, and the ordinary working power is always much more than sufficient. But in wet weather great advantage is felt from reducing the resistance of the intermediate instruments. It is obvious that when leakage exists the current will always be more powerful at any one of the intermediate stations than at the two ends, because the derived circuits gradually weaken it.

A method has lately been tried which promises good results. Instead of using coils of fewer convolutions and of less resistance at the intermediate stations, a shunt is placed across these coils to divert a portion of the current from them, and thus, by reducing the resistance of the circuit, to produce a stronger signal at the terminal station.

It may be asked whether a better result would not be obtained by winding the coils with a thicker wire, but it seems that even though the resistance be reduced to $\frac{1}{16}$ by a shunt, it may yet give readable signals; which a coil of a reduced number of convolutions would not do even if its resistance were lowered only to a fourth part of the original resistance; because in the case of the shunted coil the small portion of the current multiplied by the large number of turns of the wire has a better effect than the larger portion multiplied to a less degree. And, moreover, as a very feeble signal is sufficient to indicate a "call" where the per-

son in charge is attentive, the coils may be shunted so low that the call is just visible, when the resistance of the line will be at its minimum, and the more distant stations will be benefited to the utmost. When a call is observed, sufficient current may be admitted to allow the message to be read, and the coil again shunted for the advantage of the more distant stations.

It sometimes happens that a dozen needle-instruments, or even more, are placed upon a line of 30 miles or less. Now the resistance of 30 miles of No. 8 wire is, say, 400 ohms, while that of twelve ordinary needle-instruments is 1820 ohms. In such a case an advantage has been gained by winding the coils of the intermediate instruments with a thicker wire, so as to reduce their resistance to 420. But on account of the leakage in wet weather, it has always been necessary to place coils of the higher resistance, say of 152 ohms, at the terminal stations.

Here, again, the want of knowledge in the persons employed has prevented the adoption of this obvious method. Coils of varying resistance have been provided, but it has been found that they were generally used in the wrong places. Hence, practically, coils are made of uniform moderate resistance. Very long coils are suited for fine weather only.

437. When insulation is very defective and there is much contact, it is not desirable to use too sensitive an instrument upon the shorter circuits on the poles. As a last resource the coils of the needle-instrument may be opened, that their action on the needle may be so far lessened as to render it insensible to the leakage from the longer circuits, or the coils may be shunted, and the battery power may be a little increased to make up for the want of sensitiveness.

A faulty wire is much more effectively worked upon the double-current system than by single or unreversed currents; consequently the Morse, or sounder, is more suitable for such a circuit than the bell or the modified (two-line) printing system.

In working such a line, the signals should be made *firmly*, so as to lengthen the battery contacts. A key so constructed as to do this mechanically may be found advantageous.

A key sometimes fails from the earth contact not being fairly broken before the line contact is established.

A dirty key will frequently send a current on short circuit, but not on the line. This happens when the resistance of the line, added to that of the key, is too great for the current to overcome. The current burns or hardens the oil used on the pivots, and if too much oil is used on the key, it becomes mixed with metal-dust and dirt, so as to coat over the insulated parts.

When communication is interrupted, the sending batteries and apparatus should be tested on *short circuit* by connecting together the terminals leading to earth and line, or up and down line respectively, and moving the key. If the batteries, key, and connections be in order, the machine should move; for the line is now cut out of circuit, and is replaced by the wire used to put the apparatus on short circuit.

In sending, attention should always be paid to the galvanometer, in order to ascertain whether the current passes out to the line. A clerk should always be able to estimate the sensitiveness of his galvanometer, and to know whether the current which passes through it is weaker or stronger than usual. If weaker, the fault may be in his sending batteries; there may be a disconnection, or partial disconnection, on the line, or a defective point of contact in his key: if much stronger than usual, the fault will be earth on line: if extremely strong, the cause will be earth near his station, or perhaps in the office.

438. The cores of electro-magnets should not be in connection with the earth, as the coil is then very liable to be fused by lightning.

439. *Forked Circuits.*—It is often necessary to place in circuit three stations, whose line-wires radiate from a common centre in the manner of the portions of the letter Y. Let the station at the foot of the Y be A, the upper right-hand station B, the upper left-hand C, and the point where the three lines meet D. In the ordinary method either C or B would be placed in a loop of two wires. But if the resistances of the arms B and C do not materially differ, the circuit may be forked or bifurcated at D. If relays with soft-iron armatures are used, so that the instruments are actuated in the same direction with either positive or negative currents, no special arrangements will be necessary; but if polarized relays or needle-instruments be employed, it will be

necessary to fix a switch for reversing line, earth, and batteries at either B or C.

Let the switch be fixed at B: its normal position should be such that the instrument at B is connected up similarly to that at C, so that the signals from A, which would split or divide at D, may pass through B and C in the same direction. A can then speak either to B or C, and *vice versa*; but B cannot speak to C, because the instruments at those two stations are not joined up according to the rules laid down for needle-instruments in paragraph 359. But if the line and earth can be reversed by the switch at B, the currents will pass through B's coils in the right direction. The switch being arranged so as to reverse the batteries at the same time, B's current will now be in the proper direction to speak to C, but will be reversed at A. This is of no importance.

It will readily be seen that if it be arranged to "call" B by a given signal, that station will know that when the "call" is reversed the switch must be turned.

440. *Transmission to several stations simultaneously.*—It often happens that intelligence is required to be transmitted to a considerable number of stations, and it is obviously desirable that as many as possible should read it at the same time. With ordinary care and attention on the part of the clerks, six or more can readily read the same dispatch, if their instruments are in circuit together. If two lines branch or fork off at the intermediate station D, a translator or repeater can be placed there in the wire leading from A to C; the current from A will pass through this instrument to C direct, and will be relayed on to B by the repeater at D. The original current might be *forked* to C and B, as shown in the preceding paragraph; but the signals are more certain under the system of translation, because they are not affected by a variation in the relative insulation, or in the resistances of the several branches.

By means of a combination of the automatic system with that just described, the same perforated paper is made to transmit newspaper messages to several groups of six, or even more stations. The transmitting apparatus are arranged side by side, and the ribbon passes through each in succession.

PART X.

UNDERGROUND AND SUBMARINE TELEGRAPHS.

441. THE testing of submarine, and even of long underground lines, demands far more electrical knowledge and much greater care than is necessary for overground wires. The principal apparatus used are the differential galvanometer and resistance coils or rheostat, which have already been described: the Wheatstone balance, the Peltier and the Thomson electrometer, and the Thomson or some other delicate galvanometer.

442. THE ELECTROMETER OF MILNER OR PELTIER consists of a light wire, generally of aluminium, pivoted by a polished steel cap upon a fine point. All the parts are in metallic connection with each other, but insulated from the base board. A fragment of a sewing-needle magnetized is fixed to the moveable wire, to cause it to regain its position after having been deflected. To adjust the instrument, it is turned round until the wire lies parallel to the horizontal rod. The insulated wire to be tested is attached to the knob. It is charged by a spark, or by being touched with a wire connected to a battery of 100 cells or more; the wire of the electrometer will be repelled by the rod, and its deflection may be read off upon a graduated scale. A mirror is generally placed below the scale, and in reading off, the moveable wire and its deflection are *brought into one*, or made to coincide. As the charge escapes from the wire under test, the divergence of the electrometer will gradually decrease.

The apparatus must be very perfectly insulated, but there will always be some loss, the amount of which must be ascertained, and allowed for. The interior can be kept dry by placing in it

a saucer containing chloride of calcium. The electrometer is sometimes surrounded by a wire cage connected to earth, to cut off exterior induction.

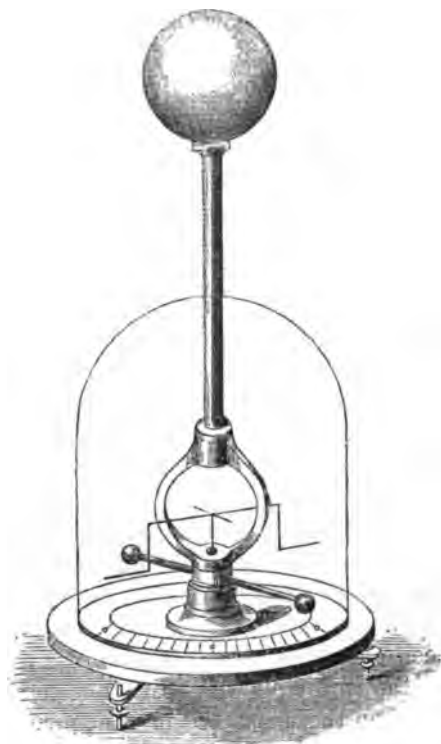


FIG. 122.

443. THOMSON'S REFLECTING ELECTROMETER.—This instrument is fully described in the report of the standards committee of the British Association for 1867.

A polished brass disc is divided into four quadrants, arranged in a horizontal plane, one of which can be moved outwards from the centre by a micrometer screw. Above the quadrants and parallel to them an insulated broad needle of thin aluminium, carrying a mirror, is suspended by a thread and is charged. If

the four quadrants are all equally electrified, the needle will have no tendency to alter its position; but if there be the slightest difference of potential between the opposite pairs, it will be repelled by the one pair and attracted by the other, and the deflection on the scale will show the difference of potential. A very small magnet is attached to the needle to give it a directive force; large magnets are fixed outside the instrument, and are capable of being adjusted to compensate the earth's magnetism to a greater or less extent, and alter the sensibility of the needle. Its sensibility is further increased by raising the potential of the needle, and, in order that its indications shall be constant, this potential must be constant also. These objects are effected by connecting the needle with the inside of a well-insulated Leyden jar, the outer coating of which is to earth. The jar is partially filled with strong sulphuric acid, which forms its inner coating, and at the same time keeps it perfectly dry, so that it does not lose its charge. Connection between the jar and the needle is obtained by a fine platinum wire fixed to its centre and dipping into the acid; the wire carries a small weight which tends to steady the needle.

A gauge is attached, to show the strength of the charge of the jar; it is a little electrical weighbridge, showing the force of attraction between two parallel plates. A revolving "doubler" is provided for the purpose of increasing or lessening the charge of the jar, so as to keep its potential uniform; the doubler acts somewhat on the principle of Holtz's electrical machine. Another check upon the constancy of the apparatus is afforded by the moveable quadrant. If all else is constant—the force of the magnets and the charge of the jar—a certain number of turns of the micrometer screw will produce in every case the same deflection of the spot of light. This electrometer may be adjusted so as to show a difference of potential as small as the tenth part of the tension of a single Daniell cell.

UNDERGROUND AND TUNNEL WORK.

444. Percha wire intended to be placed underground, or in tunnels, should be carefully tested by a delicate galvanometer for insulation, then covered with tape soaked in *Stockholm* tar.

It should also be tested for continuity or resistance before it is used. It is not often that continuity fails, but now and then a wire will be broken inside the gutta-percha.

It is useless to test for insulation *until the wire has been soaked in water twelve hours*, to give the water time to enter any small pinhole or crack which may exist. A small fault, if allowed to remain, will increase, and ultimately spoil the wire. So important is perfect insulation that a battery of 250 cells, and very delicate horizontal galvanometer, should be used for these tests.

445. The wire may be tested for insulation by ascertaining if it will retain a *charge*. Put one pole of a battery of not fewer than 50 cells to earth, and with the other pole touch one end of the wire for a moment, leaving the other end disconnected. After, say 30 seconds, put the wire to earth through a galvanometer, when the charge will pass to earth, moving the needle. If a galvanometer be not at hand, the charge may be taken on the tongue with equal certainty as to the result, and without any inconvenience from lengths under a mile. This is a very good rough test.

446. A more accurate test may be made by the Peltier electrometer. Dry the coating at both ends of the wire, pare off the outer surface of the percha, wash it with paraffin oil, or for very delicate tests coat it with solid paraffin. Connect one end of the wire to the electrometer, leaving the other free, and charge the wire by the battery as before; the needle will diverge, gradually falling back to zero as the charge escapes. The time occupied in the falling of the tension one-half is taken as the measure of insulation. A new wire of No. 18 gauge, covered with percha to No. 7 gauge, should not lose its charge in less than 10 minutes, at 50° Fahr.

But the graduation of this instrument, like that of the horizontal galvanometer (122), is not accurate, and for the same reason. It is, therefore, always necessary to ascertain by trial what angle of deflection represents one-half the tension. Divide the battery into two equal parts, charge the wire by each in turn, and take the mean.

447. When the wire proves defective, the fault, if not very minute, may be found by running it through water, connecting one pole of a battery of not less than 40 cells with a good galvanometer, the galvanometer with the wire, and the other pole of the battery with the water; when the fault touches the water the needle will move. Or the wet wire may be run through the hand, when a shock will be felt as the fault passes.

448. To find a fault in a very highly insulating core covered with a good conductor, Hooper's material for instance, the coil is wound upon two insulated reels set several feet apart, the tape is carefully removed over a space of six inches, and the rubber washed with naphtha or paraffin oil, so as to insulate the two portions of the wire one from the other. The ends are prepared by paring and coating with paraffin to prevent surface conduction; one is left free, the other is connected to an ordinary electrometer.

The two drums are next connected to earth, and the conducting wire charged from a battery or electrical machine in the manner of a Leyden jar. The earth wire is now removed from one of the drums, but left in contact with the other; the deflection of the electrometer noted to ascertain the loss by leakage in a given time. The connections are now altered so as to give a similar test to the portion of the coil on the other reel, and a comparison of the loss from each shows which of the two contains the fault. The drum containing the fault will obviously lose its charge by leakage when its outer coating is connected to earth, but retain it so long as the outer coating remains insulated, so that, if the conditions of the two are reversed, the electrometer will show which of them contains the fault.

The faulty portion is then partially wound upon the drum containing the sound portion, the coating again removed between the two and tested in the same manner. The process is

repeated until the exact spot is found. A very minute defect can be detected by this method.

449. In all tests of covered wire, the copper pole of the battery should be put to earth, so as to send a negative or zinc current to the wire; for positive currents have a tendency to lessen a fault, negative currents to increase it. The copper current oxidizes the bare part of the wire, and coats it with an imperfect conductor, while the zinc current reduces any metallic salts that may have been formed, and, as it were, electrotypes a clean surface.

Thus, an underground wire which seems perfect if tested with a copper current, will sometimes show a large amount of earth when a zinc current is used.

450. When a wire is too defective to be used, while the fault is too small to be readily found by distance tests, it may be made worse by keeping a powerful zinc current upon it for several hours. And a bad wire may be made better for a time by a copper current, care being taken, if reversed currents are employed in signalling, that the zinc or reverse current shall be much feebler than the copper or sending current; the copper current will, however, eat away the wire sooner or later.

451. In tunnels, if a fault in the covering is exposed to dropping water charged with salts of lime, the wire is frequently dissolved away for a quarter of an inch or more, the current still passing by the conducting power of the solution of copper: hence such a wire works best in wet weather. In percha-covered wire which has lain ten or fourteen years under the street, near a gas-pipe, the copper has been entirely converted into sulphite by the gas liquid. Iron wires, in tunnels through limestone rock, are sometimes corroded by drippings of water holding lime in solution. In a tunnel near Haddon Hall, in Derbyshire, the drippings have been found to contain free sulphuric acid.

452. In a tunnel the place of a fault may be found thus:— Put a current of 40 cells, or more, upon the wire at the mouth of the tunnel, disconnecting the other end. Wrap one bare end of a piece of covered wire with wet cotton waste, and connect the other to a detector in connection with the rail. Run the

waste along the tunnel wire, carrying the detector forward until the needle is deflected by the current escaping through the waste at the fault. The detector may be fixed to a staff ending in an iron point, which can be set upon the rails, which should be moistened to make good earth. If the fault is large, or the battery strong, it may be *felt* by holding the wet waste in the hand, and running it over the wire. The wire may also be cut, and tested in sections for earth.

453. It is not possible to pick out a wire from among a number in underground or tunnel work, except at the places where they are labelled. In order to find a wire, a current is sometimes sent through it from a battery having one pole to earth, and each wire is cut or pricked with a knife in succession until one is found which causes the deflection of a detector placed between the knife and earth, which is the wire sought. A great objection to this method is that it is difficult to insure the perfect sealing up of the incisions, so that faults are produced which develop themselves in course of time.

An instrument called a *wire-finder* enables any one of a number of wires to be picked out without cutting the covering. An astatic pair of needles is hung upon a hair in a box having a groove in its side, into which the wires can be placed one by one. The needles are connected by a curved bar, so that one hangs above and one below the groove, and consequently if a wire conveying a current is placed in the groove, the needles are deflected. A modification of this apparatus is a single suspended horizontal needle, directed by a bar magnet (125), so as to stand in any required position with regard to the meridian. This is placed above the wires in such a position that they can be lifted under the box containing the needle. The former instrument is the more sensitive, the latter is, perhaps, the more easy to manage. A little practice will enable an ordinary workman to use either of them.

Where there are wires among the number conveying permanent currents, the direction of the testing current must be opposite to that of the permanent current, and the direction in which the instrument will be deflected by each must be ascertained beforehand.

454. Covered wires may be worked if hung upon hooks driven into the walls of a tunnel, when they are too defective for use when lying in a trough or pipe. If they are removed into the open air, dried, tarred separately, and made into a cable wrapped with tarred canvas, they will last several years. When hooks are used to suspend a cable, it must be carefully protected from chafing at the points of suspension.

455. In testing covered wire for faults, it is more convenient to use a small horizontal galvanometer than a vertical *detector*, for 10 cells with the former will be more effective than 50 with the latter, so that the trouble of carrying a large number of batteries will be avoided. When a tunnel, a leading in, or other piece of covered work is suspected to be faulty, it should be tested in *wet weather*; as a small fault which will impede communication after rain, will not be detected in dry weather, except by a very delicate apparatus.

In testing insulated wire, it is better to accustom workmen to use a galvanometer capable of showing a sensible deflection with a minute fault, for they seldom appreciate the fact that a very small deflection upon a rough and heavy galvanometer may indicate a considerable defect; but seem rather to consider that a leakage which does not produce a considerable effect upon their particular instrument, whatever it may be, is not important enough to be sought out.

456. When wires are made up into a bundle or cable, it is frequently necessary to number or label them at both ends after they are laid. A *detector* is placed at each end, a current is sent upon one of the wires through the detector from a battery connected to earth, and the distant ends of the wires are put to earth through the second detector, one by one, until the wire conveying the current is found. Both detectors now deflect, and the person sending the current will know that the wire has been identified. The wire is now numbered *one*, and the current is sent on the second wire, and so on. It is better, to prevent mistakes, for the sender, when he sees the wire is found, to indicate its number by signal; and when there are many wires in the cable, a single-needle instrument may be used, to enable the parties to speak to each other if necessary.

SUBMARINE CABLES.

457. In planning a cable the principal points needing attention are: first, the form and strength of the sheath or outer covering, which must be suited to the sea-bottom on which it is to lie; second, the insulation, which must be perfect, for however minute a defect may be, it will increase and in time stop the communication; thirdly, the conducting power, which should be as high as possible; and fourth, the inductive capacity, which must be low. On the two latter, the speed of signalling, and therefore the commercial value of the cable, depend. Lastly, economy of material must be studied.

It is with the electrical questions we mainly have to deal; the mechanical details, as well as the weights of the conducting wire and the insulator of the principal modern cables, are given in Table XVIII.

The speed with which signals can be transmitted through cables is governed by the time required for a current to attain a given proportion of its maximum strength at the distant end, and this depends upon their length, their inductive capacity, and the resistance of their conductors.

458. *Inductive (or electrostatic) capacity.*—By the *capacity* of a condenser or cable is meant its power to receive a charge; the *specific capacity* of a *cable* is this power when considered with reference to an unit of length: thus, if in two cables, each one knot long, the one is able to take double the charge of the other, its specific capacity will be double.

459. The *specific capacity* of an *insulating substance* is its power of affecting induction as compared with that of air. If one of the two plates of a condenser has the power of causing an inductive effect upon the other equal to 1, when the plates are separated by air only, the filling the interval between them by Hooper's india-rubber will increase the induction to 3·1, and if percha is used the effect will be 4·2 greater than with air. The specific capacities of air, Hooper's rubber and percha, are therefore said to be 1, 3·1, and 4·2 respectively.

Inductive capacity is increased, in a very small degree, by increased pressure or elevation of temperature.

460. *Formula for the specific capacity of a cable.*—Thomson has calculated the following formula for the specific inductive capacity of the cylindrical condenser, which a cable forms; from the known laws of induction between concentric curved surfaces:—

The specific inductive capacity of the material used as an insulator, divided by twice the Napierian¹ logarithm, or $\log_e$, of the ratio of the diameters of the coating and conductor; a deduction of five per cent. being made from the diameter of a *strand*, because of the irregularity of its surface. Thus—let D be the outer diameter of the core, d the diameter of the conducting wire, and I the *specific* inductive capacity of the insulator

$$\text{The specific inductive capacity of the cable} = \frac{I}{2 \log_e \frac{D}{d}}$$

If a thickness of coating t produces a certain inductive capacity, to halve this capacity another layer must be added which is as much greater than t as the diameter D of the coating is greater than that of the conductor d ; that is,

If a thickness t give a capacity of 3.0

A thickness $t + t \frac{D}{d}$ will reduce the capacity to . . . 1.5

And „ $t + t \frac{D}{d} + t \frac{D^2}{d^2}$ „ „ to . . . 1.0

461. *Laws governing the dimensions of cables.*—(1.) The speed of a wave through cables of the same length varies inversely as the product of the inductive capacity and the resistance of their conductors.

(2.) In cables, similar in all respects except *length*, the speed of each, s and s , is inversely proportional to the *squares* of their respective lengths, l and l ; or,

$$s : s :: l^2 : l^2.$$

¹ Thomson uses the Napierian log. or $\log_e$, for mathematical reasons, but the ordinary log. is most generally used in cable tests. To convert an ordinary log. into $\log_e$, multiply by 2.303.

For when the length is doubled, the capacity for charge, and therefore the charge itself, is doubled: and besides this, the waves of charge and discharge have twice the distance to travel, consequently the retardation is increased fourfold.

These laws may be expressed in the following manner:—

$$s = \frac{1}{L^2 R I}$$

Where L is the length of wire, expressed in knots; R the resistance of the conductor expressed in ohms per knot; I the inductive capacity of the cable expressed in microfarads; and s the speed.

(3.) In cables alike both in material and length, but differing in the *diameters* of their conductors, d and $\bar{d}$, and insulators D and $\bar{D}$:

$$s : \bar{s} :: d^2 \log. \frac{D}{\bar{d}} : \bar{d}^2 \log. \frac{D}{\bar{d}}$$

(4.) When the lengths l and $\bar{l}$ are different also, then

$$s : \bar{s} :: l^2 \bar{d}^2 \log. \frac{D}{\bar{d}} : \bar{l}^2 d^2 \log. \frac{D}{\bar{d}}$$

Theoretically the *time of charge*, or speed of a wave, is not influenced by a variation in battery power, but practically a stronger battery more quickly raises the current to a sufficient strength to affect the receiving instrument.

In cables of similar length and of similar materials, but of different dimensions, the amount of charge is inversely proportional to the $\log. \frac{D}{\bar{d}}$. The larger the logarithm, the smaller the capacity of the cable. When the diameters of the conductor and insulator preserve the same ratio one to the other, the inductive capacity remains constant.

In perfectly similar cables, insulated at their distant ends, amount of charge is in direct proportion to their lengths, and to the number of cells used.

When insulation is perfect, charge and discharge are equal; when faulty, discharge is less than charge by the amount of

leakage. An instantaneous discharge is not affected by slight leakage, for the charge has not had *time* to escape.

462. When the diameter of the core is fixed, there is a loss in speed if the conductor is too small; because, although the coating is now thicker and the inductive capacity in consequence less, the increase of speed due to this cause is more than counter-balanced by the loss occasioned by diminished conductivity in the wire. On the other hand, if the conductor is too large, speed is lowered by increased inductive capacity in a greater degree than it is raised by lessened resistance.

There is, therefore, some proportion which gives the highest possible result, and it has been shown mathematically by Thomson that this proportion is attained when the diameter of the core being D , that of the conductor is $\frac{D}{1.649}$, 1.649 being the square root of 2.718, the base of the Napierian system of logarithms. In this case $\log. \frac{D}{d}$ is .2172.

463. But practically, as Thomson shows, the insulator of such a cable would be so thin as to be very susceptible of injury, so that the diameter of the conductor must be decreased in order that the thickness of the coating may be increased. Hence the great advantage of greater purity of copper, which gives the benefits of a thicker conductor without its inconveniences.

Speaking generally, however, when it is designed to increase speed, it is better to increase the weight of the conductor rather than that of the insulator.

The greatest proportional thickness of conductor is met with in the original Malta-Alexandria Cable, the ratio $\frac{D}{d}$ in which is 3.02; in the Atlantic the ratio is 3.18 and its logarithm $(\log. \frac{D}{d})$.502.

464. In superintending the manufacture of a cable, the first step is to ascertain if the copper wire provided for the conductor agrees with the specification as to weight and purity; this should be done before the wire is spun into a strand.

The strand is then covered with gutta-percha in lengths of a

knot, (the covered wire is technically called *core*); fifteen days are allowed for the percha to harden, and each coil is immersed in water at 75° F. for twenty-four hours. While in the tank, first, the resistance of the conductor is determined; second, the capacity of the coil; third, its insulation.

The several coils are then joined together, the joints tested, the core served with hemp, and the insulation of the served core compared with the previous tests. The core is then "laid up" into cable and sheathed, an insulation and continuity test is constantly applied during the process, so as to detect the minutest fault on the instant; the cable is also specially tested daily for insulation and resistance. As the length increases the insulation readings become, necessarily, lower, and after a certain length can be taken by the bridge in the ordinary way.

The capacity of the cable is also tested repeatedly during the process of manufacture.

THE CONDUCTOR.

465. Copper is always used, not as a solid wire, but in several wires stranded for security against breaking.

In connecting up two lengths of solid wire, each end is filed so as to form a *scarf* joint, which is well soldered with rosin then bound or wrapped closely with fine wire, again soldered and lastly re-wrapped with fine wire, soldered at each end only, so that it may pull out and keep up communication in case the joint stretches or breaks.

In joining a strand, the several wires are soldered together so as to form one solid wire, which is scarfed and treated in the manner already described.

466. The greater the conducting power of the copper strand, the higher the speed of the cable; provided the (inductive) *capacity* is not increased at the same time. But if the diameter of the conductor is increased, the capacity of the cable will be increased also, because the two coatings of the Leyden jar, or condenser, are brought nearer together by the increase of the surface of the conductor, unless indeed the thickness of the insulator is made greater by using a larger quantity of material

But if it be possible to increase the *conductivity* of the strand without adding to its bulk, the inductive capacity of the cable remains unaltered, and the full advantage of the greater conducting power is obtained. This is effected by increasing the *purity* of the copper.

467. *Purity of Copper*.—The attention which has been paid to this point is shown by the improvement which has been effected since the Malta-Alexandria Cable was laid in 1861.

Taking the specific conductibility of pure copper as 100, the conductivity of the copper of the following cables are—

1861.	Malta-Alexandria	85.39
1866.	Lowestoft-Norderney	92.32
1865.	Atlantic	93.08
1866.	Do.	94.63
1869.	French Atlantic	94.90
1870.	West Indies and Panama	96.16

The specification for the conductor of a cable states its weight per mile and percentage of conductivity, pure copper being taken as 100. These points are carefully ascertained before the wire is twisted into a strand.

In testing the purity of the copper, great attention is necessary to the following points, especially if the length of the sample be short.

The wire should not be stretched to straighten it, but may be laid in a groove cut in a plank. It should be measured and tested before it is weighed, so that it may not be necessary to coil it.

468. *To ascertain the percentage of conductivity*.—Cut off any convenient length, measure and weigh it. Let the length be 30 feet, weighing 300 grains, or 10 grains per foot, and let the resistance of the 30 feet be 700 ohms, and lastly, suppose the temperature at which the test is made to be 59° Fahr.

Find the resistance of a *foot-grain* of pure soft copper from Table XII. This will be found to be .2186 for the temperature named. As the wire weighs 10 grains per foot, its resistance

will be one-tenth of that of a *foot-grain*, and the 30 feet will have thirty times the resistance of 1 foot. Therefore,

$$\frac{.2186 \times 30}{10} = .655$$

would be the resistance of our 30 feet of wire if it were pure. But its actual resistance is .700, and by proportion

$$700 : 655 :: 100 : 93.4$$

93.4 is therefore the specific conductivity of the sample.

In these tests the temperature must be carefully observed, as it affects the resistance of the metal.

469. *To find what will be the resistance of a mile of pure copper wire of a given weight or diameter, at any desired temperature*, refer to Table XII. for the resistance of a foot-grain of wire at the required temperature, multiply it by 5,280; this will be the resistance of 1 mile of wire weighing 1 grain per foot; call this r .

Then—As the weight (W) per mile in grains of the wire whose resistance (R) is required, is to the weight of one mile weighing 1 grain per foot (5,280 grains), so is the resistance r to the resistance required.

$$W : 5,280 :: r : R \text{ the resistance required.}$$

Let it be required to find the resistance of a mile of hard copper wire .030 in. diameter, at 16° Centigrade.

According to Table IX. the weight of a mile of copper wire, .030 in. diam., is 14.26 lbs., or 99,820 grains.

The resistance of 1 foot weighing 1 grain will, at 16° Centigrade, be .2239 ohms; which, multiplied by 5,280, the number of feet in a mile, will give 1,182.2 as the resistance of a mile of wire weighing 1 grain per foot = r . Then—

$$99,820 : 5,280 :: 1,182.2 : 62.5$$

the resistance of 1 mile of copper wire .030 in. diam. at the desired temperature.

A wire just drawn has a higher resistance than after it has been annealed; unequal or partial annealing will cause a con-

siderable variation, and it is difficult to determine the precise hardness or softness of any specimen. Hence discrepancies between actual and calculated resistances cannot always be avoided.

THE INSULATOR OR DIELECTRIC.

470. The insulated wire of a submarine cable is technically called its *core*, and any piece of covered wire is frequently called a *cable* or *core*, when speaking of testing.

For economical reasons, the insulating covering is made as thin as possible; the value of a material depends, other things being equal, upon its high *conductive resistance*, or insulating power, and its low *inductive capacity*, the converse or reciprocal of which is its *inductive resistance*. India-rubber surpasses gutta-percha in both respects, but it has not been employed sufficiently long for its durability to be as satisfactorily established as that of gutta-percha. Percha is practically indestructible when under water, and insulates well enough for all purposes at ordinary temperatures; but as it becomes soft, and also loses in great measure its insulating power, at about 100°, it is unsuitable for hot climates. Hooper's india-rubber will bear boiling without injury, and does not decrease in resistance with increase of temperature in so great a degree as percha.

The processes which will now be described refer principally to percha. The core is generally made in knot lengths, and as its insulation improves considerably for the first few weeks, it is generally not tested until fifteen days after manufacture.

Two phenomena have first to be considered in insulation tests, *electrification*, and the effect of variations of temperature.

471. *Electrification or Absorption*.—When a core is tested, its insulation appears gradually to improve under the action of the battery, until after a certain interval it becomes sensibly constant, although the effect does not actually cease.

Further, if after battery contact has been broken, and the core discharged, it be allowed to remain insulated, several

successive discharges can be obtained ; especially if the testing current was powerful. This phenomenon is analogous to the so-called *residual charge* of a Leyden jar, from which, after it has apparently been completely discharged, we can, after an interval, obtain other small discharges due to the depolarization of the glass.

Taking that view of conduction which supposes that each particle is polarized and transmits its polarity to the next in succession, we know that this action will progress in a conductor with immense rapidity, and will cease as rapidly after the disturbing cause has been removed. The more imperfect the conductor the slower will the action be, until in an insulator (which may be considered as an extremely imperfect conductor or a conductor of immense specific resistance) the polarization, and also the depolarization, will occupy a considerable time.

The following table gives the leakage in divisions of a reflecting galvanometer, as observed in a knot of percha core in the factory at 64° Fahr. ; and shows the effect of electrification in increasing the apparent leakage during the first minutes of an insulation test :—

Time during which the current had been applied.	Deflection.	Time during which the current had been applied.	Deflection.
$\frac{1}{2}$ minute	430	15 minutes	278
1 "	380	20 "	270
2 "	350	25 "	265
3 "	330	30 "	260
4 "	320	35 "	255
5 "	315	40 "	255
10 "	295	50 "	250

The apparent excess of leakage during the first moments seems to arise from the current entering into and polarizing the gutta-percha ; the first layer of particles is polarized in a comparatively short time, the next in a longer interval, and so on, the action becoming more and more difficult, and occupying a longer time, as layer after layer of particles is reached. The rush of electricity is, as it were, rapid at first, decreasing

gradually until it almost ceases. After the battery is removed, the depolarization of the dielectric recharges the conducting wire, so that a succession of discharges can be obtained.

The phenomenon varies in different insulating substances, and even in different samples of the same materials, and it is much more marked in rubber than in percha. Heat so far affects it that it proceeds more rapidly at a high than at a low temperature. The higher the tension of the battery, the higher the electrification.

472. If the conductor be allowed to remain insulated (*i.e.* disconnected from earth), it becomes charged positively, as it were, spontaneously; and if it is discharged to earth through a galvanometer, a slight current passes to earth for several minutes.

The charge is directly proportional to the length of the wire, and increases as the time the core has remained insulated, up to a certain limit, which has not been correctly ascertained. The same effect occurs in a condenser of tinfoil and paraffin paper.

As a cable is always tested with a negative current, and as the spontaneous charge is always positive, its discharge coincides in direction with the testing current; for a negative current entering the cable evidently passes in the same direction through the galvanometer as a positive current leaving the cable. As this or any other charge may affect both the insulation test and the test for inductive capacity, the conductor should always be connected to earth in the intervals of rest, so that it may be completely neutral.

473. *Standard interval observed between the application of the battery and the taking the insulation test.*—It is obvious from what has been said, that unless a definite time is allowed to elapse between the application of the battery and the reading the galvanometer, insulation tests would not be comparable. The standard interval is *one minute*.

474. *Standard temperatures for insulation and resistance tests.*—As the resistance, both of metals and insulators, varies with temperature, it is necessary for the sake of comparison to fix a standard to which all tests shall be reduced. This standard is

75° Fahr., a temperature high enough to exaggerate faults in insulation, yet not so high as to injure the material.

As each coil of "core" is received from the factory, it is placed in a tank filled with water at 75°, and after an immersion of 24 hours, during which time the temperature is kept rigorously uniform, it is tested for the resistance of the conductor, for inductive capacity, or the power of becoming charged like a Leyden jar; and lastly, for insulation.

The reason for the long immersion of the core is that a change of temperature affects the resistance of percha very slowly.

475. *Reduction of tests to the standard temperature.*—In practice, the first test of the coils of core is the only one which is actually taken at 75°, all others are reduced to the standard by calculation, for it is obviously impossible to heat the large tanks which contain finished cable.

The reduction of the observed resistance of the conductor and the insulator to what it would be at 75° is effected by the co-efficients or multipliers given in Tables XIII., XV.

Suppose that the insulation resistance of the percha of a cable at 40° Fahr. be 300 megohms per knot, and it be required to find what it would be at 75°. On referring to Table XV. the co-efficient for 40° will be found to be 13·116; that is to say, the resistance of percha is 13·116 times as great at 40° as it is at 75°. Dividing 300 by 13·116, we have 22·87, the resistance at 75°.

Again, if the conductive resistance of the copper conducting wire be 1156·03 ohms at 60°, it may be reduced to 75° in the following manner by the use of Table XIII. The difference between 60 and 75 is 15, and the co-efficient for 15 degrees is 1·03139, which multiplied by 1156·03 gives the resistance required.

Conversely, the *average* temperature of a cable tank, or even the *average* temperature of the sea bottom on which a cable lies, may be found by Table XIII. from the resistance of the conducting wire of the cable, if we know its resistance per yard or mile at the standard temperature.

476. *Measurement of charge and discharge.*—Tests for capacity are more generally made by *discharge*, after charging for one

minute, than by *charge*. As shown in paragraph 152, a cable may be charged by connecting one pole of a battery to the outer sheath, either directly or through the earth, or the vessel or tank in which the cable lies; and making contact between the other pole and the conductor through a galvanometer, sharply and promptly, by means of a key. Or the key may be arranged so as to charge the cable direct when pressed, and when released discharge it to earth through the galvanometer.

It requires a little practice to use an ordinary key so as to obtain uniform results, and it is better to release it by a species of trigger, as shown in Fig. 109. The figure shows the connections for a discharge test.

The cable is supposed to be placed in a tank filled with water, in good electrical connection with the earth, or with the copper pole of the battery, the zinc pole being connected to B;

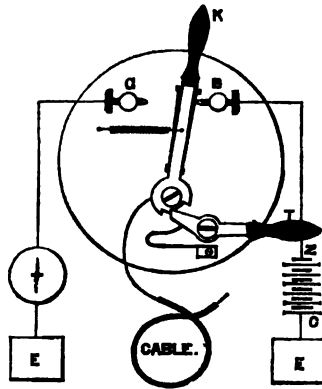


FIG. 123.

when a condenser is tested, one set of plates is connected in place of the cable, the other set to earth. The key *K* is drawn in the position for charging; when it is released by lifting the trigger *T*, the cable is discharged to earth through the galvanometer.

For a *charge* test, the galvanometer is placed between the cable

and the key, and the battery between G and the earth, the terminal B being left free.

The needle receives a sudden impulse, as if given by a blow, and therefore the forces acting upon it are proportional to the *sines of half the angles* described, which, for angles not exceeding 30° , are nearly proportional to the angles themselves. Thus, if the Thomson reflecting galvanometer, whose angle of deflection is very small, is used, the forces are proportional to the scale readings themselves.

This is only true, however, for cables of moderate length, where the duration of the current is very short as compared with the time the needle requires to complete its swing; for if its duration is sensible, it is rather a push than a blow. In cables more than 150 miles in length the currents have a sensible duration, and this method of measurement does not apply with accuracy.

477. The needle should swing slowly; it should be heavy, and be suspended very freely, and so as not to be affected by the resistance of the air. Large mirrors or large talc vanes are therefore improper, because they check the swing.

Jenkin gives the following correction for the resistance of the air when it is but slight. Observe the extent of the first swing to one side of zero—say the right; allow the needle to continue to oscillate, and note the extent of the second swing to the same side of zero, which will be less than the first. Now, as this diminution is entirely due to the resistance of the air, and as it has been effected during the swing of the needle from right to left and back again, the needle would have swung further at first by one-fourth of this amount had no air been present, because during the first swing from zero to the right the needle passed over only a quarter of the space travelled afterwards. One-fourth of the difference between the first and second deflection should therefore be added to the reading.

TESTS FOR CAPACITY.—Each coil of core is tested while in the 75° tank, to ascertain if its capacity agrees with the standard determined on, and if it prove too high, the capacity of the insulating material is too great or its thickness too small.

The test is made with a low power, generally 10 cells, and its accuracy will therefore be affected by the electrification caused by previous tests, or by any charge which may remain in the core. It is therefore generally taken before the insulation test, which requires 200 cells or more.

The capacity of a cable is found by the amount of charge it is capable of receiving, as compared with a standard condenser (page 83.)

As charge is directly proportional to the potential of the testing battery, the number of cells may be varied, until equal deflections are obtained both upon the condenser and the cable; when their capacities will be directly as the number of cells used for each test. Care must of course be taken to choose cells which are precisely equal, or to ascertain their relative potentials.

It is necessary in all cases in which comparative tests are made with varying battery power, to know exactly the relative potentials used; for this is not always proportional to the number of cells.

478. *To obtain the potential of a whole battery in terms of that of a standard cell.*—Charge a condenser by a single cell, discharge it through a reflecting galvanometer or other sufficiently delicate instrument, noting the deflection obtained. Charge the condenser by the whole battery, and *shunt* the galvanometer until the deflection is the same as that given by the single cell. Then, the number of times the tension of the battery exceeds that of the cell first tested is given by the formula $\frac{g}{s} + 1$, where g is the resistance of the galvanometer, and s that of the shunt.

For example, it is required to know the potential of a battery of 200 cells used to test a cable, in terms of the single cell used to take the *constant* of the galvanometer.

Let $g = 5,400$ ohms and $s = 30$ ohms, then $\frac{g}{s} + 1 = 181$; that is to say, the 200 cells are equal only to 181 such cells as the single one with which the constant was taken.

Or take a discharge d from the single cell; then, after shunting

the galvanometer to $\frac{1}{10}$ or $\frac{1}{100}$, according to the number of cells to be tested, take a second discharge D .

Then $\frac{10 D}{d}$ or $\frac{100 D}{d}$ = the tension of the entire battery.

For example, if the discharge from the single cell gives a deflection of 120 divisions, and the battery of 200 cells 180 divisions with the $\frac{1}{100}$ shunt, then

$$\frac{180 \times 100}{120} = 150 \text{ the value of the 200 cells.}$$

479. *To find the capacity of a cable by comparison with a condenser, whose capacity (in microfarads) is known—*

(1.) When the capacity of the condenser and cable are nearly equal, the charge or discharge of each can be read directly from the galvanometer, and will be proportional to the swing of the needle, corrected by the method given in par. 476.

Let C be the capacity of the standard condenser in microfarads, D the deflection or swing of the needle from its charge or discharge; c the capacity of the condenser or cable to be measured; and d the swing from its charge or discharge. Then

$$D : d :: C : c.$$

(2.) When the capacities are unequal, so that their charge cannot be read off from the same scale, and c is greater than C .

Take a reading from C ; then from c . Shunt the galvanometer by resistance coils until the deflection obtained from c is the same as that previously obtained from C , then

$$c = \frac{g + s}{s} C.$$

Where g is the resistance of the galvanometer, and s that of the shunt.

When C is greater than c the process is reversed, the galvanometer being shunted in taking the reading from C , and

$$C = \frac{g + s}{s} c.$$

The greater the swing, the less the effect of a small error of observation. In using a reflecting galvanometer, the deflection may be taken across the whole length of the scale, instead of from its centre. To eliminate error resulting from the unknown resistance of the wires which connect the rheostat used for the shunt, a known resistance may be added to the galvanometer, so as to permit the use of a shunt so large that the resistance of the connecting wires may be neglected.

(3.) The test may also be made with the differential galvanometer, by a modification of the arrangement shown in Fig. 66 (page 176). Connect the condenser in the place of the resistance coils, and the cable in the place of the line-wire, using a key to make contact between the other ends of the coils and the battery.

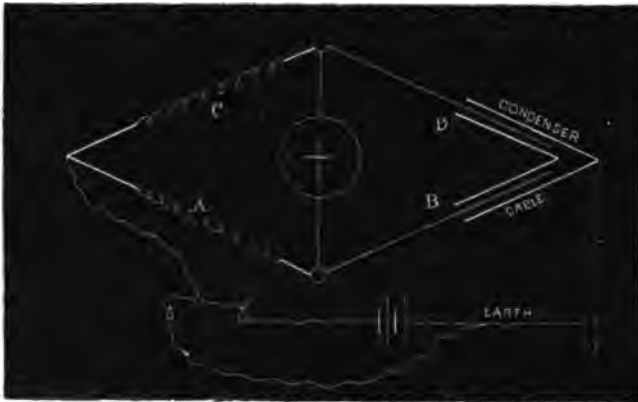


FIG. 124.

When the capacity of the cable is greater than that of the condenser, the coil to which the former is connected is shunted until the effect of the charge in each coil is alike, and the needle remains unmoved; when the capacity of the condenser, multiplied by $\frac{g+s}{s}$, (where g is the resistance of one coil of the galvanometer,) gives the capacity of the cable. If the cable is less in capacity than the condenser, the coil to which the latter is connected must be shunted.

The formula may be generally expressed thus:—

Let s = the resistance of the shunt.

g = that of one coil of the galvanometer.

c = the lesser charge or discharge.

C = the greater charge or discharge.

Then $s : s + g :: c : C$.

(4.) Or by the bridge. Let the arms A and C (Fig. 124) be resistance coils; B the cable, whose capacity is to be measured; D the inner coating of the standard condenser. The outer coating, the iron sheath of the cable, or the water in which it lies, and one pole of the battery are connected together or put to earth. The key is shown in the position for charging and is supposed to be released by a trigger as in Fig. 123; when released it discharges the condenser and cable through the bridge. The resistances in A and C are adjusted until a balance is obtained, when the capacity of the cable is found by proportion in the usual way.

480. *Distribution of charge*, when two cables or condensers are connected together.—If a charged cable or condenser be joined to one not charged, the charge will divide itself between the two in proportion to their respective capacities, the potential becoming the same in both.

Let C be a standard condenser charged to potential T , and let x be another condenser or cable, and t their joint potential when combined.

Then $t : T :: C : C + x$,

and $CT = Ct + xt$.

The capacity of x will be—

$$x = \frac{T - t}{t} C.$$

In a number of cables connected together at their charging ends, with their distant ends insulated, the charge is equal to what would have been obtained had they been joined in one continuous length.

When a cable is very long, the time occupied by its discharge is very much greater than that required by the condenser. Resistance is then placed in the condenser circuit to delay its discharge.

481. *To find the capacity without the aid of a condenser.*—Shunt the reflecting galvanometer, and add resistance until a readable deflection is obtained with the battery with which the cable is to be charged. From these data calculate what total resistance R (including that of the galvanometer and battery) would be necessary to reduce the deflection to one degree, which is the unit deflection of a mirror galvanometer.

Next, count the number of oscillations which the needle makes per minute when swinging freely, that is, not under the influence of a current. Let t be the time of half a complete oscillation.

Lastly, let d be the deflection produced by an immediate discharge; then

$$^1 \text{Capacity} = 2 \frac{t \sin : \frac{1}{2}d}{3.1416 R} \text{ microfarads.}$$

(Jenkin.)

482. *Measurement of charge in short pieces of cable.*—It is often necessary to measure the capacity of short lengths of wire, small condensers and samples of insulating materials, the charge and discharge from which are far too feeble to affect a galvanometer, even if a powerful battery is employed.

But although a single discharge is unable to affect the galvanometer, a succession of discharges following one another so quickly that the needle has not had time to regain its zero before a fresh impulse is given it, will each drive the needle a certain distance, and the sum of their effects will produce a steady deflection. The value of a single discharge can be found by dividing the deflection at the end of a given time by the number of discharges.

The apparatus for this purpose is called a "whip," and in its simplest form is a spring, connected to the condenser to be measured, which is caused to vibrate very rapidly between two studs, one in connection with the battery, the other with the galvanometer. As the spring vibrates it first charges the condenser from the battery, and then discharges it through the galvanometer to earth.

¹ 3.1416 is π , the ratio between the diameter and circumference of a circle.

In this case the charge, instead of being represented by a sudden impulse, is indicated by a constant deflection, and is therefore proportional to the sine of the angle described by the needle, instead of half its sine. Siemens gives the following formula for the value of these deflections.

If a is the sine of the angle through which the sine galvanometer must be turned to bring the needle to zero, n the number of charges or discharges per second, e the electromotive force of the battery, we have

$$\text{Capacity} = \frac{a}{e} n;$$

and if the velocity of the apparatus remain the same, the capacities of two cables, or of a cable and a condenser, are directly proportional to the sines of the deflections obtained from each.

By placing an insulated spring upon the opposite end of the lever, so as to vibrate between a second pair of contacts, the apparatus can be made differential.

483. *To find the weight and thickness of insulating material required to produce a core equal in inductive capacity to a given cable whose conductor is similar, but which is insulated with a different material.*

Let the diameter of a percha core be .348 in., the diameter of the conductor .102 in., it is required to find what thickness and weight of Hooper's material is required to produce a core of equal capacity, using a conductor of the same diameter.

(1.) To find the diameter. The specific inductive capacity of percha is 4.2, and that of Hooper's material 3.1, air being 1 (461); and the logarithms of the ratio $\frac{D}{d}$ in cables of equal

capacity, where the conductor is similar in both, will necessarily be in the proportion of the specific capacities of the insulating substances.

Then to find x , the required diameter of the core, say

$$4.2 : 3.1 :: \log. \frac{.348}{.102} : \log. \frac{x}{.102}$$

by which x is found = .253 nearly.

(2.) To find the weight per knot. The specific gravity of the two materials are as 5 to 6, percha being the lighter of the two. By Clark's formula (Appendix) the weight of percha per nautical mile is $\frac{D-d^2}{481}$ lbs. which for the present cable is $\frac{253^2-102^2}{481} = 111$ lbs. Then $5 : 6 :: 111 : 133$. The diameter of the required core is therefore .253 in. : and the weight per knot, 133 lbs.

484. *INSULATION TESTS.*—A perfect core tests alike with either copper or zinc to earth, but a faulty core tests worse with a negative than with a positive current.

The leakage of even a moderately good core is far too small to be tested directly by the bridge or differential, until many miles have been completed. The separate coils and the shorter lengths of cable are tested by the deflection of a reflecting galvanometer, and 100 to 200 cells of a constant battery, often of the Minotto form.

It is usual to specify for a resistance of 200 million ohms per knot at 75°; but even in a core of 148 lbs. of percha and 107 lbs. of copper per knot, a resistance of 300 millions is easily obtained.

485. *Effect of pressure on insulation.*—A cable insulated with percha always improves in insulation after it has been laid, partly because the temperature of the sea is lower than that of the tank, and partly because of the pressure of the water, which increases the resistance of percha between 2.3 and 2.6 per cent. for every 100 pounds on the square inch. It is said that the Atlantic Cable improved during submersion 7 per cent, for every 100 fathoms it sunk. In the factory, at 75°, the insulation was 390 million ohms per knot after one minute's electrification; when laid, 2,437 millions; and after 30 minutes' electrification, 7,000 millions. It is said that it now tests about 5,000 millions per knot.

Jenkin says (*N. B. Review*, Jan. 1867), "that the difference in conductibility between the percha of the Atlantic Cable and an equal bulk of copper, is as great as the difference between

the velocity of light and that of a body moving but a foot in 6,700 years.

486. *Test by deflection.*—(1) Take the constant of the galvanometer (320) with *one* cell, through a standard coil of 1,000 ohms, after shunting it to $\frac{1}{1000}$. This will be equivalent to the deflection which would be obtained with one cell through one million ohms ($1,000 \text{ ohms} \times 1,000\text{th shunt}$), if the galvanometer had not been shunted. Let the deflection be 100 divisions of the scale.

(2) Next find what deflection the whole testing battery of 100 cells would give through one million ohms. If all the cells were equal in strength, and all equal also to the standard single cell, a simple multiplication by 100 would suffice, but it seldom happens that all the cells of a battery are alike in power; and therefore the real tension of the 100 cells may be less or more than one hundred times that of the cell used in taking the constant. Find the potential of the whole battery in terms of the single cell used in taking the constant, by the method described in paragraph 478. We will, however, suppose the potential to be 100.

(3) Put the zinc of the battery in perfect communication with the water of the tank, connect the copper to the conductor of the core, and test for leakage in the ordinary way (316) by reading the deflection of the galvanometer; let the deflection be 40 divisions.

Now the galvanometer with one cell through a resistance of one million ohms shows a deflection of 100 (1). This is the *constant* of the galvanometer. But if the 100 cells had been used, the deflection through the million ohms would have been $100 \times 100 = 10,000$; and the reading with the 100 cells through the core is 40 (3).

Then by proportion $40 : 10,000 :: 1,000,000 : 250 \text{ megohms}$, the insulation of the core.

Or, let s be the value of the shunt ($\frac{1}{1000}$).

r the resistance of the standard coil (1,000).

c the constant of the galvanometer.

E the potential of the battery in terms of the single cell used in (1).

d the reading obtained on the cable.

i the insulation resistance of the cable.

$$\text{Then, } \frac{s \times r \times c \times E}{d} = i.$$

It is obvious that any other resistance and any other shunt could be used in taking the constant. In cases where the shunts have not been arranged to reduce the sensitiveness of the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, or some other convenient multiple; or where, as is often the case, the resistance of the galvanometer or shunt is liable to change; their resistances must be determined, and the *value* s of the shunt ascertained, by the formula $\frac{g}{s} \times 1$; where g and s represent the *resistances* of the galvanometer and of the shunt.

The observed resistance multiplied by the length in knots will give the insulation resistance per knot.

487. *Insulation test by fall of charge.*—Insulation resistance can be determined from the loss of static charge, by means of the galvanometer or the electrometer. This test is comparative only, and will not give the resistance unless the electrostatic capacity of the core is known.

In testing by the swing of the galvanometer, charge the cable from a battery for a minute, discharge immediately, noting the deflection or swing of the needle (Fig. 123). Charge again, leave the cable *disconnected* one minute, and again discharge; the difference gives the leakage in one minute.

Or, instead of reading the discharge, read the charge. Then, after a minute, charge again, the cable having been left disconnected in the interval by placing the key K (Fig. 123) midway between the contact points G and B ; the second deflection will show the quantity which enters the cable to make up for that which had escaped during the minute. If insulation is perfect, there will be no second deflection. A somewhat heavy needle answers best for these experiments; if a Thomson with vanes of talc offering great resistance to the air is used, its readings will not be perfectly accurate, but corrections can be made to allow for the resistance of the air.

The loss may, as it were, be magnified by reading the charge in the first instance upon a shunted galvanometer and increasing its sensitiveness before recharging. For instance, the first charge may be read with a shunt of 1-10th, the last without any shunt; in which case the leakage will be multiplied by ten, or rendered ten times more apparent.

To test by the reflecting electrometer, connect the cable to the instrument and to the battery, note the deflection, then disconnect the battery and note the deflection after the minute. The fall of tension is beautifully shown by this apparatus, as the angle of deflection is always proportionate to the potential of the charge remaining in the cable, and shows its diminution moment by moment.

488. *Fall to half-charge.*—The system of testing the insulation of cables by ascertaining the length of time required for the charge to fall one-half or any other fraction, has many advantages; it is independent of the length of the cable, and of the resistance and electromotive force of the battery employed, nor is it necessary that the constants of the instruments should be ascertained, all which causes render it eminently suited for ascertaining the insulation of a submerged cable, and ascertaining its relative condition from year to year.

The ordinary method of testing by half-charge is to divide the testing battery into two equal parts, and to take an immediate discharge from the cable with each half in succession in the manner described in the next paragraph, taking the mean, which shows the deflection the cable will give when the charge from the *whole* battery has sunk to one-half. Charge the cable with the whole battery, and by a series of trials ascertain the time which elapses before the discharge sinks to that given by half the battery.

If an accurately graduated galvanometer be employed, it will not be necessary to halve the battery; an immediate discharge is in this case taken with the whole battery, and its amount divided by two for the half-charge.

The electrometer shows at a glance when the tension has fallen to one-half.

489. Clark has devised a simple method of making this test

with any ordinary galvanometer, which is well suited for use on board ship or on the sea-shore.

Two condensers are employed, each having exactly the same electrostatic capacity. The cable is first charged from a battery for 10 or 15 minutes, to get rid of the effect of absorption. During this time one of the condensers is charged from the same battery, and then placed momentarily in connection with the second condenser, when the two will become charged exactly to half-tension, the charge dividing equally between them (480). It only remains then to place them in connection with the cable through any galvanometer, at the time when it may be expected to have fallen to half-tension; if this is done at the right moment, no charge will pass through the galvanometer in either direction; if the connection be made too soon or too late, a slight charge will pass from the cable into the condensers, or *vice versa*, and the operation must be repeated. By a simple key, these connections are all made at pleasure by one motion of the finger, and in one or two trials the time of falling to half-charge is obtained with great precision.

The capacity of the condensers should not be large (about .2 microfarad), so that if the test is made too soon it shall abstract but a very small portion of the charge. As the contact is of extremely short duration, there is no time for leakage to take place from the condensers, which would vitiate the result.

Before testing, put the cable to earth for several hours, to get rid of any charge which may accidentally have accumulated in it. Use as low a battery power as possible, for energetic discharges are apt to demagnetize or reverse the needle; and when the ordinary insulation test and the discharge test are both used, the discharge must be taken first, because the high battery power used for the former will cause so much absorption as to increase the discharge.

490. *To calculate insulation resistance, R, from loss of charge.*—Let f be the capacity of the cable in microfarads. c the initial charge, as shown by an immediate discharge after charging for one minute. c the charge remaining after charging one minute,

and afterwards leaving the conductor insulated for a minute ; then—

$$R = 26.06 \frac{1}{f \log. c - \log. c} \text{ megohms.}$$

Example.—A knot of French Atlantic cable had an electrostatic capacity (f) of 0.3992 microfarads. The instantaneous discharge (c) gave 332 divisions of the galvanometer scale, the discharge after one minute's insulation (c) 202. The resistance was therefore—

$$R = 26.06 \times \frac{1}{.3992 (.5211 - .3054)} = 300.3 \text{ megohms.}$$

When the fall is to *half-charge*, $c = \frac{C}{2}$ then

$$R = 86.56 \frac{t}{f} \text{ megohms,}^1$$

where t is the time of falling to half-charge.

491. *To calculate the leakage of a cable from the known leakage of an equal length of another cable, composed of similar materials, but in different proportions.*—Let D and d be the diameters of the core and conductor whose leakage a has been ascertained, and D' and d' the corresponding dimensions of the cable whose leakage a' is required. Then—

$$a' : a :: \log. \frac{D}{d} : \log. \frac{D'}{d'}.$$

When the two differ in length, calculate as for equal lengths and reduce by proportion, leakage increasing directly as the length.

Insulation tests by accumulation.—When the core to be tested is very short, or the leakage excessively small, the *accumulation* process is adopted.

492. *The testing of joints.*—A joint should insulate as well, or nearly as well, as an equal length of the perfect core, and the object of the test is to ascertain if this be the case. Now the leakage, even from a considerable length of good core, is too

¹ "Electrical Formulae." Clark and Sabine. P. 35.

small to affect the galvanometer; but although the electricity which escapes moment by moment cannot be measured, still if it were possible to store up the loss during a minute, and compel the accumulated loss to pass all at one moment through the coils, it would produce a sensible deflection.

In order to effect this, recourse is had to induction. A metallic trough, sufficiently large to contain two or three feet of the core, is suspended by straps or rods of polished ebonite, two or even three feet long. A small condenser is attached to increase its inductive capacity, and enable it to store up the electricity which may leak through the percha. The testing battery, of not less than 200 cells, is insulated in a similar manner, and all loss over the surface of the conducting wires is prevented by paring their ends, so as to expose a fresh clean surface, or even by coating them with hot paraffin.¹

To ascertain if the apparatus is sufficiently insulated, the trough and condenser are charged, and the swing of the needle, from an immediate discharge, noted. They are then recharged and left free for a time equal to that to be occupied by the test, and again discharged. The difference in the swing shows the loss in the time, and should be very small.

The joint is placed in the trough, a negative current is applied to the cable, and the positive pole of the battery is connected to the outside coating of the condenser. Any leakage which may occur through the percha is by this arrangement accumulated in the condenser, and may be discharged through the galvanometer after any given interval.

A six-feet length of the core without a joint is now substituted, and tested in the same manner, the insulation of the two should be the same.

It is possible to find how much is lost by defective insulation during the joint test itself; but as both core and joint are subjected to the same conditions, and the object is simply to see if one insulates as well as the other, this precaution does not seem to be absolutely necessary.

¹ Paraffin oil may be used in an emergency, but never except where the part coated can be cut away, as the oil has a softening effect on percha.

To make the test. 1st. Place the joint in the trough—leave one end of the cable free; connect the copper pole of the battery to the galvanometer; connect the other terminal of the galvanometer to the trough; and, finally, charge the cable by applying the zinc pole.

The charge within the cable acts inductively upon the natural electricity of the trough, the wire being in fact the inner, and the water the outer coating of a Leyden jar. A portion of the negative electricity of the water is set free, and an equal quantity of the positive is held fast or disguised by the negative charge within the cable. The free electricity is at once neutralized by the action of the battery; if it were not so arranged, it would increase the apparent leakage from the cable, being of a similar sign.

The deflection or swing due to the discharge being instantaneous, it follows that if the needle *remains* deflected after the discharge, the joint is very bad, or there is leakage over the surface of the percha. The latter may be conducted to earth so as not to interfere with the test, by wrapping an earth wire round the core a few feet from the free end.

2nd. Without disturbing the charge of either cable or trough connect one coating of the condenser to the trough, the other coating to the + pole of the battery, the zinc being to the cable as before.

Any negative electricity which may leak from the cable will now accumulate in the condenser. Allow one minute for this.

3rd. Disconnect the condenser from the trough and battery, and discharge it through the galvanometer. If the trough and other parts of the apparatus have been well insulated, the swing will show the accumulated leakage from the portion of core under test. It is evident that these changes must be made by perfectly insulated keys and commutators.

This method somewhat differs from that ordinarily adopted. It is usual to put one pole of the battery to earth; but in this case leakage takes place over the whole cable, however long it may be. By the plan described, the leakage is confined to the part in the trough, and the whole force of the battery is concentrated there, and the apparent leakage exaggerated.

493. *Joint testing by electrometer.*—In joint testing, an electrometer is frequently used instead of a galvanometer for ascertaining the amount of "accumulation." Its great advantage over the galvanometer is the absolute knowledge it gives of what is passing throughout the entire duration of the test. With the galvanometer it is impossible to know anything of what may have happened during the test, or its probable result, until the time for taking the discharge has arrived. The electrometer

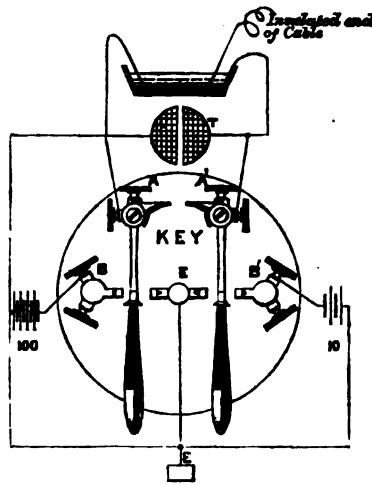


FIG. 125.

shows one what is taking place from the commencement, the gradual accumulation is observed, and any fault or accidental touching of wires is at once noticed.

The connections are similar to those for the galvanometer, and the alteration is simply in the observing instrument.

The use of an ordinary condenser has been abandoned; for in practice it is found that where the accumulation from a joint is very small, the condenser is liable to give fallacious results. It frequently accumulates of itself, and if it has been used for any other tests, it is most difficult to clear it of its charge, all condensers being made of material that retains its charge most obstinately. The testing room being generally at some little

distance from the factory, it is found in practice that the *lead* to the trough possesses sufficient capacity to be employed as the condenser. When a lead is thus used it is essential that its insulation should be perfect, and it is advisable to have it placed along the ground so as to increase its capacity, and at the same time to remove it to a distance from the charging wire, for when leads are near one another there is sure to be induction between them.

Fig. 125 shows the arrangement for this form of the test. *A A'* are levers mounted on ebonite pillars and furnished with long ebonite handles tipped with bone or ivory. These levers are pivoted so that they can be brought into contact either with *B*, or *E* and *B'*, or *E*, respectively. *B* and *B'* are terminals insulated in the same manner as the levers *A A'*, while *E* is a plate mounted on a brass pillar. These five pillars are screwed into a brass foot-plate connected to earth. The ivory tips to the lever handles are intended to prevent the excitation of electricity which would occur if the hand was allowed to slide along the ebonite in the act of moving the levers, no such effect being produced when they are moved by the ivory.

Brass is used for the foot-plate to prevent surface conduction between the several levers and terminals, by conveying all leakage to earth. The electrometer is Thomson's reflector.

The joint in the trough is connected to the terminal *A*, its other end being insulated. The trough is connected to one half of the electrometer and to the key *A'*; the other half of the electrometer is connected to the earth. The terminal *B* is joined to a battery of 100 cells or more, the opposite terminal *B'* to a battery of 10 cells. When at rest the lever *A'* is pressed to the left, keeping the electrometer in short circuit through the earth connections.

In testing a joint for leakage, the insulation of the trough is made sure of by pressing the lever *A'* to *B'*, charging the trough and electrometer to the potential of the 10 cells; as soon as the spot of light on the scale is steady, the lever *A'* is freed, when the deflection will fall gradually in proportion to the leakage of the trough; if the fall be rapid, the trough and all connections should be cleaned; if, however, the fall be slow (there must be

always some loss, this depends more upon the state of weather than anything else) the joint may be tested.

Short-circuit the electrometer to discharge it, and when it is at zero open the circuit, pressing at the same time the arm A to B so as to charge the cable and joint with the 100 cells; the induced charge of the trough will be then seen, and should be noted. Again, short-circuit the electrometer, and when the spot is steady at zero, open the circuit and watch the electrometer during the time fixed for the accumulation; say one minute, or two minutes. It will be seen that the potential of the lead and trough, which was at first nil, is now slowly increasing, and is of the same sign as the charging current. The potential at the end of the fixed time is the amount of accumulated loss through the joint during that interval. This should be subsequently compared with the loss from six feet of core tested in the same manner.

After the accumulation has been observed, short-circuit the electrometer, and observe the inductive discharge on breaking battery circuit at B.

It often occurs, when there are several wires in the cable, that the apparent leakage is greater from the joint which is first tested, than from any of the other joints tested at the same time. This arises from the charge in the first wire acting upon the others inductively. The wires not under test should therefore be put to earth until they are wanted, and the condenser and trough should be perfectly discharged between each test.

It will be understood that the results are simply comparative, not absolute; all that the method effects is to show the difference between the insulation of a joint and that of any other part of the core.

494. *Precautions in testing.*—As the leakage from a good cable is extremely small, it follows that unless the batteries, keys, and other apparatus used to test it are perfectly insulated, the loss through them may be almost as great as that of several miles of core. The leakage over the surface of the percha must also be prevented by carefully paring the ends of the core, and even washing them with paraffin oil or coating them with solid paraffin, when very accurate tests are required.

The keys must be mounted on ebonite, and the batteries placed on ebonite supports, or slung by percha straps.

The wires leading from the batteries or cable tanks to the testing room must be *perfect* as to insulation, or their loss or leakage ascertained before each set of tests, with the minutest care. They must not be so near as to influence one another inductively.

The support for the galvanometer should be of massive brick or stone, placed east and west on a sound foundation, so as to prevent vibration; and because of the disturbing effect on a magnet of masses of iron in motion, the testing room should be as far from the factory as possible, or tests can be made only when the machinery is at rest.

When the galvanometer is adjusted for excessive sensibility by lessening the directive force of the needle, the zero point is liable to alteration from the twisting of the suspending fibre. It is therefore better to use a higher battery power and a less sensitive needle.

The Leclanché battery is very suitable for insulation tests, but the Daniell or one of its modifications must be employed for measuring low resistances, such as that of the copper conductor. Great care must be taken to prevent powerful currents passing through the galvanometer, as they may seriously interfere with its magnetism and its adjustment. In testing for insulation, the galvanometer is short-circuited to prevent the inductive charge passing through it. The short circuit can be broken at the half minute, and the deflection read at the end of the minute.

495. In using the balance for the resistance of the copper conductor, the ratio between the arms A and C may conveniently be 10 to 100 ohms when the cable is under 4 or 5 miles; for longer cables it may be made 100 to 1,000 ohms; the resistance can then be read correctly within one-tenth of an ohm.

The galvanometer is shunted to reduce it to the needed amount of sensibility, and low battery power is employed.

When the resistance is unknown, the current passing through the galvanometer may sometimes be powerful; in all tests, therefore, the galvanometer key should not be firmly depressed, but tapped lightly and quickly, so as to allow a very slight current

to reach the coil; its *direction* can then be ascertained; whereas if the key were held down, the spot of light would be driven across the scale suddenly, and would continue to vibrate to either side, so that its direction would be unknown, and much time would be lost in waiting its return to zero.

If adding or decreasing resistance in the balance do not alter the direction of the deflection, the connections will have been incorrectly made.

When the connections are properly adjusted, it will be seen that when the resistance of the measuring coils is too great, the deflection is to one and the same side of zero, and to the opposite side when too small; let then the arrangement of the wires be noted, so that the direction of deflection may in all cases indicate at once whether the coils have too much or too little resistance; this will save much time and trouble.

After the direction of the deflection has been brought under command, alter the measuring coils until the light is brought near zero, then increase the sensitiveness of the galvanometer by lengthening its shunt, and complete the measurement. In these final tests the key may be firmly pressed, but in all cases it must be released when the resistance is about to be altered, as the alteration may cause too large a movement of the light. This is especially necessary when those resistance coils are used, in which the shifting a plug breaks the circuit.

The plugs must be kept scrupulously clean, and the contacts firmly made.

As the resistance of copper wire is considerably affected by alterations of temperature, it is convenient to use a galvanometer of German silver wire, which is far more constant, for capacity or insulation tests.

METHODS ADOPTED IN TESTING THE FRENCH ATLANTIC CABLE OF 1869.

496. (A.) TESTS APPLIED TO THE CORE.—The core, after it has been manufactured about fifteen days, is immersed in water, at a temperature of 75° Fahr., for twenty-four hours, when careful observations are made on each coil.

OBS. 1. The *resistance* of the conductor is determined. In the cable in question this was about 3.25 ohms for each coil, and was compared with a standard of 3.25 ohms, also immersed in water to secure uniformity of temperature. In diagram 1, ef is a platinum-iridium wire stretched parallel to a metre scale divided into millimetres. The ends of this wire are soldered to massive copper bars, to which the resistance coils R and R' are connected. These coils have each a resistance equal to that of 2.333 metres of the platinum-iridium wire.

The testing battery is one zinc-platinum cell; the galvanometer resistance is .5 ohm only; the key is so arranged as to close the battery circuit first, then that containing the galvanometer; r' is the standard of 3.25 ohms; r the coil of core under test; and m a contact piece, sliding upon the stretched wire ef . The commutator is so arranged that either R and r' , R' and r can be connected (as shown by the diagram), or, reversing the connections, R and r , R' and r' . To observe, press the key and slide m along ef until no current passes through the galvanometer, then reverse the commutator and take another reading. The connections should be made by mercury cups.

Let the reading $em = x$ in the first observation, when R and r' , R' and r are connected; and x' in the second, when the connections have been reversed.

Then the resistance of the core $r = r' \frac{2.833 + (x' - x)\frac{1}{2}}{2.833 - (x' - x)\frac{1}{2}}$

where x and x' are expressed in millimetres (1).
 $(x + x')\frac{1}{2}$ should equal 500 ohms nearly.

OBS. 2. The *insulation-resistance* of the percha after one minute's electrification is determined both with negative and with positive currents from a battery of 100 cells, allowing a sufficient time between the two observations for the core to discharge itself perfectly. The current is passed through the galvanometer into the conductor, the opposite end of which is free, and the deflection is read after one minute. The galvanometer is, in the first instance, short-circuited, so as to prevent the charge passing through it. If d is the deflec-

tion and c the constant of the galvanometer, the insulation-resistance = $\frac{c}{d}$. . . (2).

OBS. 3. The *constant* c is found in this way. (Diagram 3.) A condenser is charged with one cell and discharged through the galvanometer (g) with shunt s' , giving a deflection d' .

The condenser is next charged with 100 cells and discharged through the galvanometer with shunt s'' , giving a deflection d'' .

The current from one cell is passed through 10,000 ohms' resistance, and then through the galvanometer shunted with s''' giving the deflection d''' .

$$\begin{aligned} \text{Then } c = d''' \frac{d''}{d'} \times \frac{g \times s''}{s''} \times \frac{s'}{g + s'} \times \frac{g + s'''}{s'''} \\ \times (10,000 + \text{resistance of cell}) \quad . \quad . \quad . \quad (3). \end{aligned}$$

OBS. 4. The *rate* at which the core *loses a charge* when the ends are insulated is determined in the following way:—

The coil is charged for 15", then insulated, and after having been insulated 60" is discharged through the galvanometer, giving a deflection d' .

It is then recharged and immediately discharged, giving a deflection d .

$$\text{The loss per cent.} = 100 \frac{d - d'}{d} \quad . \quad . \quad . \quad . \quad (4).$$

and the effective mean insulation during the time the coil remains insulated being R ,

$$R = \frac{60}{2 \cdot 303 \times \text{capacity} \times \log. \frac{d}{d'}} \quad . \quad . \quad . \quad (5).$$

R is in megohms when capacity is in microfarads.

OBS. 5. The capacity of each coil is determined thus:—

A condenser of a capacity of 0.355 microfarad is charged, and discharged through a galvanometer with a shunt s' , as in Obs. 3,

giving a deflection d' . Then a coil which, in Obs. 4, gives the deflection d with the shunt s , has a

$$\text{Capacity} = d \frac{g+s}{s} \times \frac{s'}{g+s'} \times \frac{1}{d'} \times 0.355 = a d \quad . \quad (6).$$

s is generally alike for all the coils, so that

$$\frac{g+s}{s} \times \frac{s'}{g+s'} \times \frac{1}{d'} \times 0.355$$

is first found. Calling this expression a , the capacity of any coil is $d a$.

The same battery is used for 4 and 5. It consists generally of 50 cells.

(B.) TESTS APPLIED TO THE CABLE.—The several coils of core are jointed together, placed in cold water, and tested before they are served.

OBS. 6. *Tests of joints* (diagram 6).—The joint is placed in an insulated trough partly filled with water, one end of the conducting wire is connected to a key, the other is left free. A metal plate placed in the water is connected by an insulated wire with one side of a condenser having a capacity of 0.05 microfarad, and also with one electrode of a reflecting electrometer. The other electrode of the electrometer is connected to the remaining side of the condenser and with the earth.

The observation is made thus. The two electrodes are connected together, and the battery is put on the coil. The electrodes are now separated and the battery is *reversed*, and the deflection caused by the inductive charge consequent upon the reversal of the battery is observed; to see that the connections in the factory are in order, and that there is the usual length of core in the trough.

The electrodes of the electrometer are again connected together until 15" have elapsed since the reversal of the battery; they are then separated, and after an interval of 60" the deflection (d) of the electrometer is observed.

The joint is then removed, and a standard consisting of six feet of the core is placed in the trough in its place, tested in a similar way, and the deflection obtained compared with that from the joint.

Now, if the electrometer be so adjusted that each division of its scale corresponds with a difference of potential of $\frac{1}{n}$ th of the battery power used, and if the capacity of the condenser and connecting wires be c microfarads, the insulation resistance of the joint, in megohms, will be very nearly equal to $\frac{60}{cd}$. . (7)

and if the length of the core placed in the trough, and that of the joint itself, are known, the insulation of the joint can be compared with that of an equal length of perfect core at 75° Fahr.

OBS. 7. The *insulation-resistance* of the severed core is determined by method 2, the zinc pole being put to the cable and the copper to earth; and is reduced to 75° Fahr. by the formula

$$\text{Log. } \frac{\text{Resistance at temperature } t}{\text{Resistance at temperature } t'} = (t' - t) \cdot 0506 (8.)$$

It is then compared with the former tests.

The temperature is carefully taken by a thermometer which has been compared with a standard.

OBS. 8. The completed cable is tested daily for the *resistance of the copper conductor*; 10 cells being used and the electric balance. (Diagram 8.)

R is a resistance that may be varied from 0 to 10,000 ohms. R' and R'' resistances of 10 and 100, or of 1,000 and 10,000 ohms. The battery is first connected, shortly after, the galvanometer, and the resistance R is altered until no current flows through the galvanometer. When this is the case, the resistance of the conductor of the cable $= R \frac{R''}{R'}$. . (9), from which the resistance of the connecting wires must be deducted.

The resistance so found divided by the length of cable in circuit, gives the resistance per unit of length; which is compared with previous determinations under Obs. 1, after having been reduced to 75° Fahr. by the following formula:—

Resistance at t degrees = resistance at t' degrees

$$(1 + (t - t') 0.00402) . . . (10).$$

OBS. 9. The insulation-resistance is also determined daily as in experiment 2; as a rule, opposite currents are used on alternate days. The constant is, however, usually taken by direct deflection, in the manner shown by diagram 9, in which s is a shunt, R , R' , e and e' , resistances. The current passes through e and e' , and then splits between R' and R , together with g and s ; call the deflection of g , d . After reading d , e is removed, and the shunt s diminished until the deflection becomes the same as before. Let the diminished shunt be s' . Then the

$$\text{constant} = \left(\frac{(R + R' + g'') \times (R + R' + g')}{R' (g'' - g')} \times e + R' \right) \times \frac{d}{R + R'}$$

$$\text{where } g'' = \frac{s g}{s + g} \text{ and } g' = \frac{s' g}{s' + g} \quad . \quad . \quad (11).$$

OBS. 10. The inductive capacity is determined as in experiment 5. The cable is charged with 10 cells, and discharged through the galvanometer with properly arranged shunts; the discharges are compared with those obtained with the same battery from a condenser of 0.1 microfarad (see equation 6).

OBS. 11. The rate of loss of charge is determined thus (diagram 11). One end of the cable is insulated, the other is connected to one electrode of a reflecting electrometer; the opposite electrode is attached to a switch by which it can be joined to either pole or battery of 50 or 100 cells, or to earth direct. The electrodes are first connected together, and put to earth, then separated without altering the earth connection; the electrometer being watched, and the process repeated, until the cable is found to be perfectly discharged.

Secondly, the electrodes are again connected together, and the cable is charged for 20", and the deflection read after 60". The loss of charge per cent. is then equal to $\frac{\text{deflection}}{\text{constant}} \times 100$,

where the constant is the ratio of the whole battery power to the electromotive force, indicated by a deflection of one division on the electrometer scale.

OBS. 12. This constant is found thus (diagram 12). The current passes through a small resistance s , and then through a

large resistance R to earth; the electrometer being connected as in the diagram, the deflection (d) is observed.

s is then reduced to $\frac{s}{2}$ and R to $\frac{R}{2}$ and the deflection (d') read, when the

$$\text{constant} = d \frac{R + s}{s} \left(1 + \frac{d - d'}{2d' - d} \right) \dots (12).$$

The arrangements should be such that $d - d'$ is small.

In testing the French Atlantic Cable, R was usually about 57,000, and s 10,000 ohms.

The constant being found, the loss per cent. is $100 \frac{d}{\text{constant}}$ and the insulation per knot

$$= \frac{60}{2.303 \times \text{cap. per knot} \times \left(2 - g \left(100 - \frac{100 d}{\text{constant}} \right) \right)} \dots (13).$$

which is the same expression as in equation (5).

C. TESTS ON BOARD SHIP.—After the cable is shipped, the copper resistance is taken by method 8, and the *temperature* is calculated thus.

OBS. 13. Let R be the resistance of one knot of *pure* copper wire of the same diameter and weight as the core at 75° Fahr.

Let R' be the resistance per knot as originally found by Obs. 1, in the tank heated to 75° .

And let R'' be the resistance per knot as observed on board ship.

Then the temperature of the copper

$$= \frac{R' - R''}{R'' - R' + R} \times \frac{1000^\circ}{4.02} \text{ Centigrade.}$$

The temperature, as thus found, is compared with that of the water in the cable tank as determined by a thermometer.

OBS. 14. *The insulation resistance*, which has now very much lessened, owing to the increased length of cable under test, is taken by direct deflection, the effect of electrification being observed by keeping the battery current on for 20 or even 30 minutes, taking readings every minute.

The cable is then put to earth, and when discharged, a similar series of readings is taken with the battery reversed. If the cable is perfect, the whole set of readings should be identical with either current.

OBS. 15. *Capacity*.—On board ship with a long cable in circuit a different method from that adopted in Obs. 5 is necessary. The cable is connected as shown by diagram 15; the resistance R being large, yet greatly smaller than the insulation-resistance of the whole cable. It should be such that the cable shall lose half its charge in 60 seconds.

The battery key is closed, and after the current has been applied about ten minutes, the deflection (d) is read.

The battery key is then opened, and 60 seconds after, the deflection (d') is observed.

$$\text{The capacity of the cable} = \frac{60}{\frac{R' \left(R + \frac{sg}{s+g} \right)}{R + R' + \frac{sg}{s+g}}} 2.303 \times \log. \frac{d}{d'}$$

Where R = the resistance coil already mentioned.

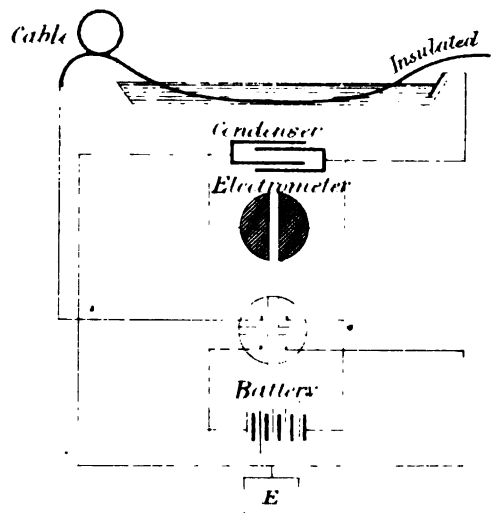
R' = the insulation-resistance of the cable, after an electrification for as long a time as the battery had been kept on before insulating the cable to observe.

R and R' being in megohms, the capacity will be in microfarads. (Forde.)

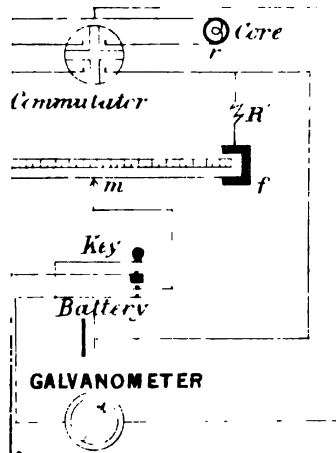
TESTING FOR THE DISTANCE OF FAULTS IN CABLES.

497. *When the conductor is bared so as to make earth, but not broken*.—The length and resistance per knot of the conducting wire being known, it may be tested for earth from each end (372); but whenever a second wire is available to form a loop, the loop test (371) should be employed, as it is independent of the resistance of the fault, and is therefore more accurate than any other.

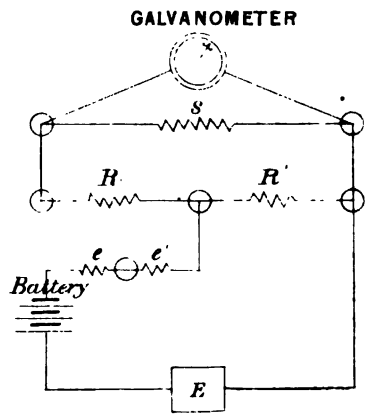
Testing by the differential.—This method is fully explained at section 365.



Obs. 6.

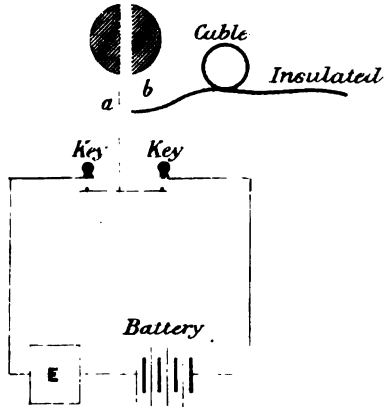


Obs. 1.



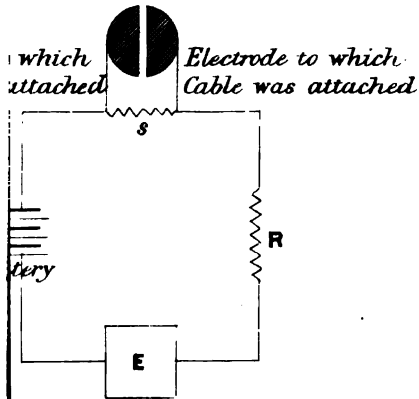
Obs. 2

ELECTROMETER.

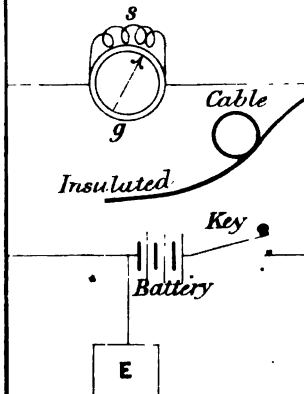


Obs. 11.

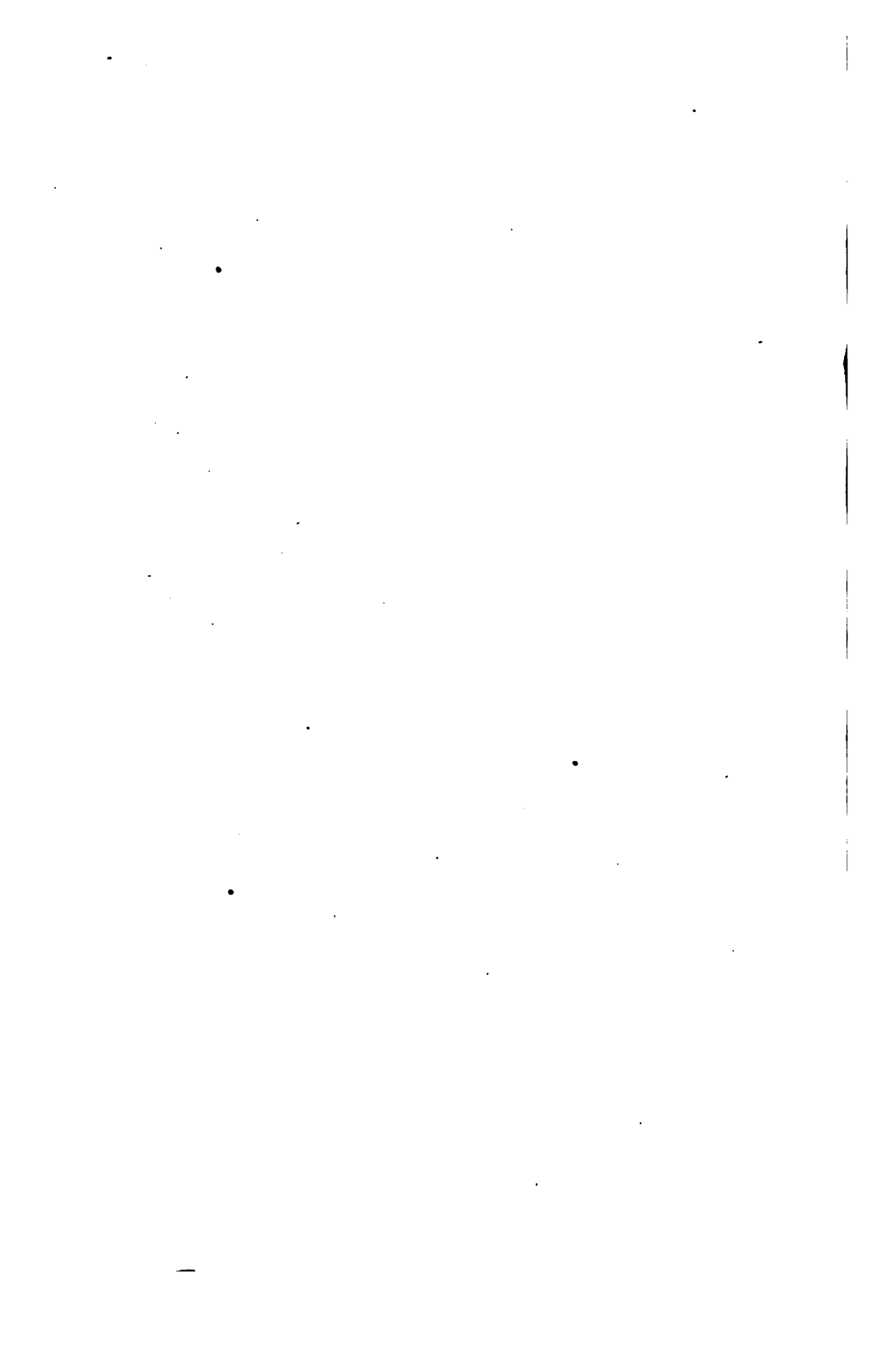
ELECTROMETER



Obs. 12.



Obs. 15



498. *When the cable is broken.*—This is a much more difficult problem. When the cable is broken, both ends of the conductor are generally exposed, but occasionally one end is broken within the percha.

When the copper touches the iron sheath the fault will offer little or no resistance, and its distance may be found by a simple resistance test.

But this rarely occurs, and there is considerable difficulty in ascertaining the distance, especially when only a short length of copper wire is exposed.

The difficulty of the problem arises from several causes.

(1.) As the ends are exposed, they form galvanic elements or batteries with the iron sheath and the salt water, so that a + current flows from the cable, through the testing galvanometer, to earth; this is steady and constant if the cable is not disturbed.

(2.) We have to deal with two unknown resistances: that of the wire itself, and that between the exposed end and the earth; the first is constant, the second very variable, because—

(3.) The action of the current alters the resistance at the point at which the metal touches the water, by coating it with substances of variable conductivity; and at the same time the apparent resistance is still further affected by the currents of polarization set up by these substances.

The action which takes place can be shown by placing a piece of cable in a glass filled with salt water, and applying a current from 40 or 50 cells, one pole of the battery being connected to the iron sheath, the other to the copper conducting wire. The portion of the cable connected to the zinc gives off a stream of hydrogen, while the other becomes coated with a chloride of the metal. Thus, if the negative pole is connected to the conductor, and the positive to the sheath, chloride of iron is formed, and if the connections are reversed, chloride of copper is produced.

Let us now connect a galvanometer to the cable, in such a manner that the current from the cable battery of copper and iron in salt water, called the "cable current," shall deflect the needle to the *right*; the iron element being of course always on the earth.

If a negative current is now sent into the cable, its direction coincides with that of the cable current, and does not affect the direction of the deflection.

But the superior force of the testing battery overcomes the cable battery, and polarizes its elements. The copper wire becomes coated with hydrogen, the iron sheath with chloride of iron, so that when the testing battery current is cut off, and the cable battery is again free to act, its action is reversed, and the needle moves to the *left*, under the influence of the current of polarization.

But the hydrogen gradually enters into combination and disappears from the wire, the polarization ceases, the needle returns towards zero, passes it, and finally takes up its former position to the right, under the influence of the cable battery in its normal state.

On the other hand, if we test with copper instead of zinc, the needle is deflected to the left, the cable battery again acts as a decomposition cell, but the polarization is now in an opposite direction, the copper being coated with its chloride, and the iron with hydrogen. When the testing current ceases, the needle therefore moves to the right, and continues permanently deflected in that direction, because the normal current from the cable battery is now in the same direction as the current of polarization.

If we apply a succession of short zinc currents, after the wire has been coated with chloride, the needle will take up a right-hand deflection after the battery contact has been broken; but the deflection will decrease after each test, and will finally be reversed. The deflection to the right is due to the polarization set up by the chloride of copper; each application of the zinc current reduces a portion of this chloride, and assists also in removing it mechanically by the action of the hydrogen; until after a time the chloride disappears, and is replaced by hydrogen. The sign of the polarization is then changed, and the direction of the needle changed also. But there is a moment when the opposite actions of the hydrogen and chloride are apparently balanced, so that the cable battery is inert, and the end of the wire unpolarized and probably uncoated. Then, and

then only, can its correct resistance be determined. The object of the following method of test is to produce this condition.

499. *Lumsden's method.*—The test for distance is best made with a differential galvanometer. First ascertain the approximate resistance in the ordinary way, and clean the end of the wire from the dirt and salts with which it will be coated, by applying a zinc current for several hours, occasionally reversing it to get rid of any deposit of soda which may occur. The surface will be roughened by the re-deposit of the copper which has been dissolved, and will therefore more readily throw off the hydrogen evolved by the zinc current. Next, apply a positive current for the purpose of coating the wire with chloride of copper, and finally test with the negative current. The action of the current set up by the chloride of copper makes the resistance appear less than it really is; but as the chloride is gradually reduced by the testing current, in the manner which has just been explained, the resistance will appear to increase, moment by moment, and the resistance coils must be lengthened, unit by unit, to balance it, so as to keep the needle as nearly as possible at zero. The increase of apparent resistance, and the consequent movement of the needle, is slow and gradual so long as the hydrogen is employed in reducing the chloride; when the reduction is nearly complete the movement is more rapid, and when the chloride has disappeared hydrogen is evolved, and the apparent increase in resistance is enormous and almost instantaneous, and the needle moves over with a bound. Unless, therefore, the resistance of the cable has been carefully balanced, so as to follow the variation of the current throughout, the test will not succeed, because the neutral condition lasts too short a time to permit the adjustment of the resistance coils.

In the first stage of the test the motion of the needle is stopped, or even reversed, by adding one or two units to the resistance of the coils. But when the change is about to take place, this addition has no effect on the needle, and the coils will then show the true resistance of the cable.

In any case a certain dexterity is required, which can only be obtained by practice; but fortunately the practice may be had conveniently upon an artificial fault, or a piece of percha wire

in a tin can, filled with salt water, and connected to a set of resistance coils. Induction does not affect the test, and as in any ordinary cable the insulation is practically perfect, its resistance can be represented as accurately by a rheostat as by an actual cable. The higher the tension of the battery, the less does the opposing current of polarization affect the result, for its force seldom exceeds two or three cells. The measurement is therefore made with a battery of as high a tension as can be conveniently procured, 60 cells or more.

If the fault is at a short distance add resistance, 100 ohms or thereabouts, to prevent a too sudden change of polarization.

500. The behaviour of a fault varies with the length of wire exposed; a short end polarizes and depolarizes very rapidly, its changes in resistance are correspondingly rapid and its resistance great. If the end is long, the changes are slower and are more readily observed; the resistance of the fault is also less.

After having well studied the changes of the fault itself, make an artificial fault by placing a piece of the cable core in a tin can filled with salt water, and alter the length of the exposed wire until it behaves in the same manner as the cable, and then find its resistance, which will be very nearly the same as that of the real fault; so that the distance of the break will be the tested resistance of the cable less that of the artificial fault. This method is not, however, of much service.

501. *Clark's approximate method.*—It is a convenient plan to form a table of the resistance of exposed ends of various lengths, with 6 and 60 cells, adding line resistance by a rheostat, using the negative current and allowing the end to take up its maximum resistance. The tests with 6 cells will be always higher than those with 60, that is to say, the resistance of the end will always appear higher when tested with the lower power, and the difference between the apparent and real resistance will also increase gradually, as the length of the cable itself or the resistance added by the rheostat increases, when the length of exposed wire is constant.

If a cable is found to give, with 6 and 60 cells, two results corresponding to some two in the table, it is probable that the length and resistance of the end exposed is the same as that of

the artificial fault used in the formation of the table, and therefore that the resistance between the testing station and the fault is equal to the resistance added to the artificial fault.

So much, however, depends upon the manner in which the tests for the tables were taken, or upon what we may call the "personal equation" of the observer, that every one should form a table for himself. The cable must be treated in precisely the same manner as the artificial fault, and therefore no table will be perfectly correct unless it is made just before the cable is tested, in order that the precise manipulation may not be forgotten.

502. The following table was formed with a piece of the Dunwich-Zandvoort cable, in a vessel of sea-water, and shows the manner in which the apparent resistance varies with the tension of the battery, the resistance added by the rheostat to represent the cable, and the length of the exposed wire.

Inches of copper wire exposed.		$\frac{1}{2}$		$\frac{1}{2}$		$\frac{1}{2}$		$\frac{3}{4}$		1	
No. of cells used.		6	60	6	60	6	60	6	60	6	60
Units of line added.	25	296	96	270	84	259	79	233	75	226	72
	50	325	121	299	109	287	104	261	100	255	98
	100	385	172	357	160	345	155	319	151	312	148
	150	448	223	416	211	403	205	376	202	369	199
	200	502	274	475	262	461	256	433	253	426	250
	250	561	325	533	313	519	307	489	304	482	301
	300	620	376	592	364	577	358	546	355	539	352
	350	679	427	651	415	636	409	603	406	596	402
	400	738	478	709	466	694	460	660	457	653	453
	450	797	529	767	516	752	510	716	507	709	503
	500	856	580	825	567	810	561	773	558	766	554
	1000	1440	1090	1406	1076	1392	1070	1339	1066	1332	1062

503. Temperature affects a distance test to a considerable extent by altering the resistance of the copper (80). Should the temperature of the sea vary only ten degrees, it would alter the resistance 2·1 per cent.

504. When a cable is broken, no current, beyond that which may be necessary to prove that the fault is in the cable, should be applied to it until it is tested from the shore. A newly

broken end is clean and in a fit state for the operation, but the action of the sea-water quickly covers it with substances which interfere with the test, especially if a current is applied improperly, and it is, moreover, useless to test for distance through a land line.

If the fault is tested in the ordinary way before the exposed end has become coated, its proper resistance will be about two or three miles less than that shown by the test.

505. *Another method.*—The effect of polarization may be eliminated by applying a negative current for 10 or 12 hours, interrupting it occasionally and giving a short positive current ; watching the differential galvanometer to ascertain when the cable current ceases ; then taking a resistance reading as rapidly as possible, and ascertaining whether the needle again comes to zero, showing that the polarization has not recommenced. It is necessary to adjust the resistance coils before the test, so that it may be made without loss of time ; because if the polarization current be allowed time to establish itself, the test will be incorrect. The cable current is generally equal to one Daniell cell, and therefore the larger the number of cells used in testing, the more accurate will be the result. The final tests are made alternately with negative and positive currents, the *mean* of which is taken.

In a rapid tideway this test should be made at slack water or the chloride may be washed off, causing the resistance to appear too great. If the conductor is a strand and the water penetrates to any distance under the percha, the first tests will be the best.

506. *INDUCTION TESTS.*—If one of the wires has very high resistance, or is broken within the insulating sheath, it is possible to *seal it up* by a positive current from 50 to 100 cells continued 10 or 12 hours, so as to insulate it sufficiently to compare its charge and discharge with that from a known length of the same cable, or from a condenser of known capacity (479).

In attempting to insulate the end, the current must not be interrupted for an instant, nor must it be *reversed*, for a reversal, however short, will destroy insulation.

507. *De Sauty's method*.—The capacity of the portion of the cable between the tester and the fault may be found by the method described in paragraph 480, placing the cable in B, the standard cable or condenser in D, and varying the resistances in A and C, until the needle remains unmoved when the two condensers are discharged to earth, showing that the *inductive circuits*¹ B and D are equal. When the condenser or cable in D has a less capacity than the cable in B, the resistance inserted in A must be proportionately less than that in C, to allow a greater quantity of electricity to pass through the arm A in a *given time*, in order that the longer cable may be charged to the same potential as the shorter one in the *same period of time*. Then by the law of the balance, $A : C :: B : D$. If the condenser equals one mile of the cable, the distance is given in miles without further calculation; the length of cable represented by it being, in fact, the *unit* by which the distance is measured.

508. *Varley's method*.—Ascertain which takes the greater charge, the cable or the condenser. If it be the cable, connect it to one coil of the differential galvanometer, and shunt it by resistance coils; connect the condenser to the second coil of the galvanometer. By means of a key take charge or discharge tests, varying the resistance of the shunt until the needle is unmoved.

Then, let s be the resistance of the shunt,

g that of one coil of the galvanometer,

c the length of cable represented by the condenser,

l the length of the cable,

$$s : s + g :: c : l.$$

By the same method the length of a cable may be found from that of a similar cable of known length. Thus, if the length of the *shorter* wire be known, multiply it by $s + g$ and divide by s , which gives the length of the longer wire; or, if the length of the *longer* wire be known, that of the shorter may be obtained by multiplying the longer length by s and dividing by $s + g$, $\frac{s + g}{s}$ being the multiplying power of the shunt used.

¹ *Inductive circuits*.—See Webb, "Electrical Accumulation and Conduction."

TESTS USED DURING THE LAYING OF CABLES.

509. For cables not exceeding 200 or 300 miles in length the following plan may be adopted :—When there are several wires in a cable, they are looped together into a continuous length. If the number is even, an instrument is placed on shore, in one of the loops, for the purpose of communicating with the ship. The junctions of the several wires on shore are carefully sealed, and the instrument is fixed on a well-insulated stand. This is to make certain that the insulation test shall not be interfered with. If the number of wires is odd, one of them is set apart for communicating.

All tests are made by the ship, and the shore may not speak or send a current unless by permission of the ship.

The wires being looped, a small battery and an ordinary vertical galvanometer, both well insulated, are connected between the two extremities. The galvanometer remains permanently deflected, and serves as a test for continuity, without interfering in any way with the insulation test.

For insulation, a battery of 100 cells or more is connected, one pole to earth, the other to the stud marked B of the trigger key (Fig. 123), the opposite stud G being to earth.

The lever of the key is connected to cable through a marine galvanometer. When the lever of the key rests on the battery stud, the cable is under test for insulation or being charged ; if the lever is released, and allowed to fall back to the opposite or earth stud, the cable is discharged through the galvanometer. But before charging or discharging the cable, the vertical galvanometer must be short-circuited, or it may be demagnetized.

510. The following plan has been proposed for maintaining a constant continuity test at the same time with the usual insulation test in a single wire cable.

The battery and galvanometer for the insulation test are placed on the ship, and the land end of the cable is connected to an insulated spring. A pendulum is made to vibrate between

this spring and a similar one connected to earth through a galvanometer. The bob of the pendulum contains a condenser which, by vibrating between the end of the cable and the galvanometer, alternately charges itself from the cable and discharges itself through the galvanometer.

The intermitting contacts with the condenser would appear on the ship's galvanometer like slight contacts with earth, and the shore needle would indicate the passage of intermitting currents, so long as the cable remained perfect. The currents would gradually lessen and finally cease if the wire parted inside the percha, so as to become insulated, and would cease suddenly if the broken end were exposed, so as to allow the charge within the cable to pass to earth.

511. But for long single-wire cables a more refined method is required. The system adopted for the Atlantic and all other recent long cables is that of Mr. Willoughby Smith.

It is first necessary to describe the Resistance Slides.

Resistance slides.—These are used in order to charge a condenser to a certain fraction of a given potential, or to vary its charge to balance the varying charge of a cable.

It has already been shown that when one pole of a battery is put to earth and the other pole is connected to a wire of high resistance, such as a long telegraph wire, the distant end of which is also to earth, the potential (tension) falls regularly along the wire, becoming zero at the distant end, and the potential of any point can be ascertained by an electrometer of sufficient accuracy.

It therefore follows that if a divided scale be attached to such a wire, a condenser may be charged to one-half, one-tenth, or any given fraction of the maximum potential of the battery, by connecting it at the proper point.

An artificial line is constructed by a large number of resistance coils. If there be 100 coils all equal in resistance (100 ohms each), the potential will vary by $\frac{1}{100}$ th part at the junction of each pair, and thus, by attaching a condenser to any junction, it may be charged to any fraction of the total potential of the battery within $\frac{1}{100}$ th part.

If a second similar set be connected between any two coils of

the first, the difference of potential between these coils will again be subdivided into 100 parts, and thus a reading of $\frac{1}{10000}$ th may be attained.

512. *Tests during the laying of the Atlantic Cables.*—Fig. A represents the arrangements for the shore, and Fig. B those for the ship. (See diagram.)

Shore tests.—In Fig. A the end of the cable is shown as connected with a switch *s*, which can be made to touch either of the three terminals marked 1, 2, 3. It is usually connected with 1. The cable end is also permanently connected through a high resistance (20 or 30 megohms), to a galvanometer *G*, and thence to earth.

When a permanent current is sent from the ship's testing battery, the end of the cable being almost perfectly insulated is raised to a high potential, but sufficient current will leak through the resistance to affect the mirror galvanometer *G*. The resistance should be adjusted so as to allow a deflection of about 200 divisions on the scale of *G*.

But if the cable conductor become broken, or bared in the slightest degree, a much feebler current or none at all will pass the resistance; this arrangement then serves as a continuity, and also for an approximate insulation test for shore.

This high resistance is not an ordinary coil, but is made of selenium or of percha, and its permanence is not well assured. A second means is therefore provided by which shore can ascertain whether the potential of the cable is maintained. Terminal 1 leads to the back stop of a key *K*, the lever of which is connected to the upper plate of a condenser *C*, whose lower plates are connected through a galvanometer *G*¹ to earth. When this key is depressed, it discharges the upper plates to earth and produces a deflection on *G*¹.

But, as the upper plates are permanently in connection with the cable when the key is at rest, the condenser is charged to its potential, so that the discharge and deflection consequent on pressing the key shows the potential of the cable for the time being. This test serves as a check upon the first.

When it is desired to converse with the ship, the switch *s* is moved to terminal 2, leading to the upper plates of a second

condenser c^1 , the lower plates of which are connected to a second switch s^1 , which can itself be brought into contact with one or other of the terminals 4 or 5, leading to a reversing key K^1 , and a galvanometer G^2 respectively. To receive from the ship the switch s^1 is turned towards G^2 ; when any alteration in the potential of the cable is communicated to the condenser c^1 , and is indicated by a movement of the galvanometer needle either to the right or left, according to whether the charge is raised or lowered, by the reversing key on the ship.

To speak to the ship, s^1 is moved to terminal 4, leading to a reversing key, which by charging the lower plates of condenser c^1 , either positively or negatively, raises or lowers the potential of the cable, and produces single-needle signals upon the ship's galvanometer G (Fig. B).

It will be seen that during signalling the insulation of the shore end of the cable is unaffected, all the signals being produced by induction through the condensers.

Again, if the switch s is turned to terminal 3, it is connected to one side of a reflecting electrometer E , the other side of which is connected to a set of the slides already described, by means of which the electrometer can be charged to any required fraction of the potential of the testing battery B . If then the slide is moved until the electrometer stands at zero, its position on the resistance coils will show exactly the potential of the cable in terms of the testing battery.

But it is necessary to eliminate the error which would arise from a variation in the testing battery, and for this purpose a set of ordinary resistance coils R , and a third galvanometer G^3 , are provided. The resistance of these coils is from time to time altered so as to keep the potential of the slide, as shown by the deflection of G^3 , uniform; so that its indications may remain perfectly constant from day to day.

Thus if the minutest fault occur, the time of its occurrence can be ascertained and its locality calculated.

Ship tests.—It is desirable that the tests on board the ship should be less complicated than those on shore, and they are consequently arranged in the more simple form shown in

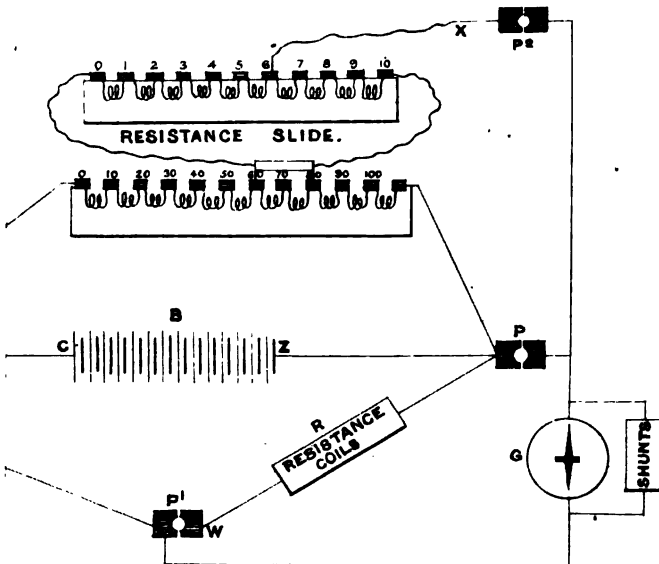
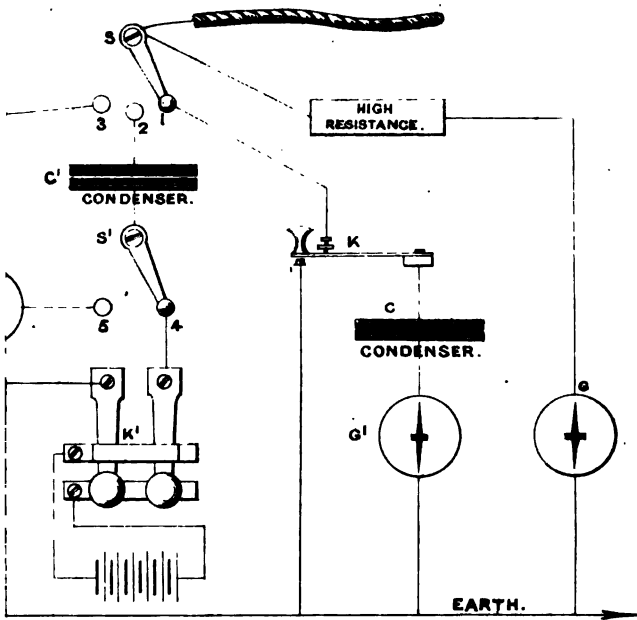
Figure B. They consist of a Wheatstone's bridge, in connection with battery B, one pole of which is connected with the point P, from which, the plug P being out while the plugs P^1 and P^2 are in, the current will be divided and pass; a part by the resistance coils R, to the point w, and a part through the right-hand section of the slide and coils to the point x, forming two sides of the bridge—the other two being represented by the resistance of the insulating sheath of the cable, and the left-hand section of the slides. When the plugs P^1 and P^2 are in, there is also a circuit from w to x, through the galvanometer α , completing the combination. Now the shore extremity of the cable being always insulated, the means of determining the insulation of the cable itself are very simple: the galvanometer G will of course indicate when the resistances in the four sides of the Wheatstone's bridge are balanced, under which circumstances they will form a simple proportion, of which three of the factors, viz. the resistance in the coils R and the right and left sections of the slide, are known, and from which the fourth, the resistance of the insulation of the cable, can be found.

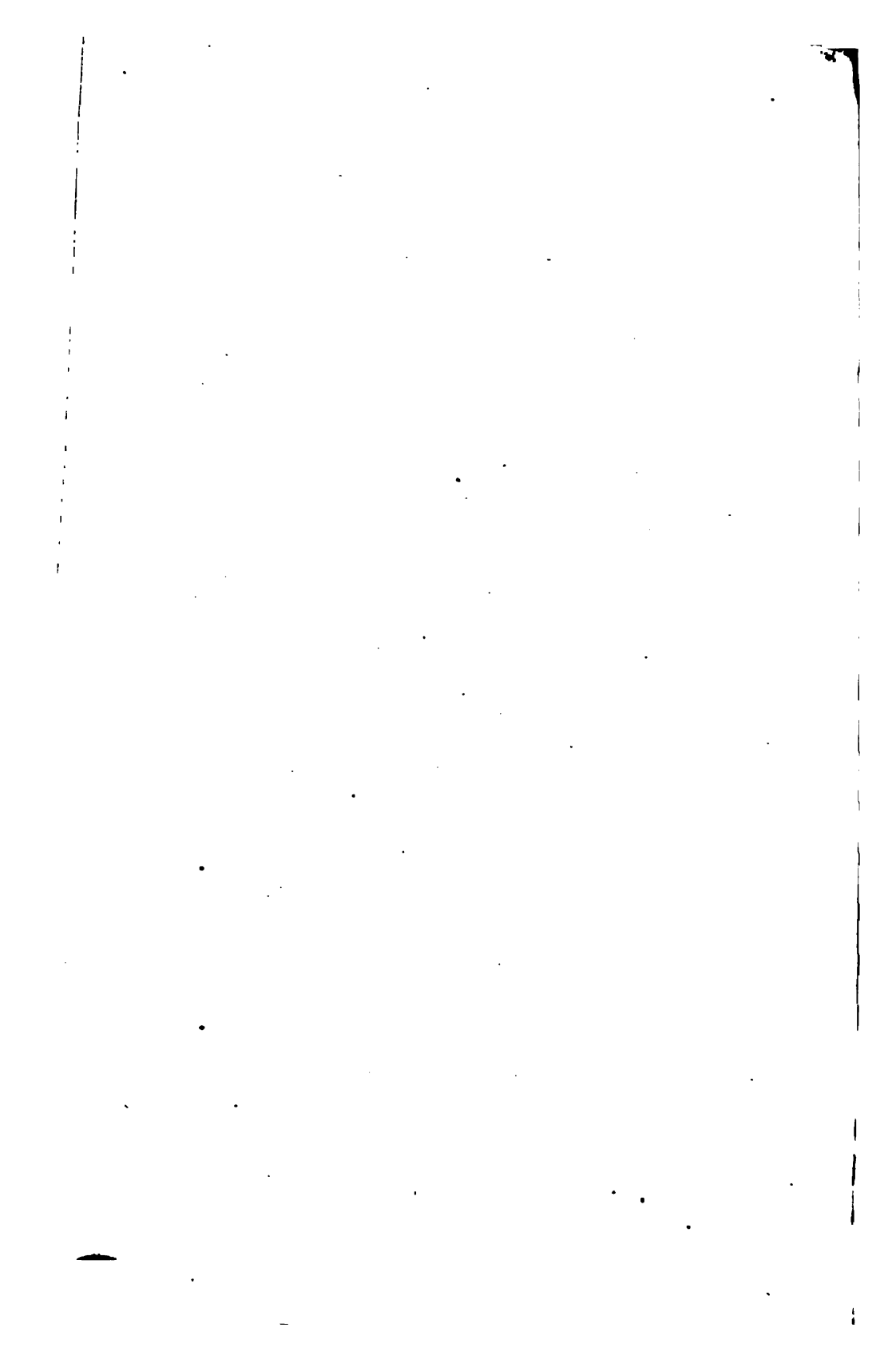
The resistance of the coils R is not altered, but the galvanometer G is brought to rest by the adjustment of the moveable part of the slides. If any injury causing a leak should occur in the cable, the Wheatstone's bridge will have to be used in determining the position of that leak by simply balancing the resistances, as already described, when the difference of resistance in the cable thus determined will, in conjunction with the observation at the shore end, give the required data for calculating the position of such leak with considerable accuracy.

If anything should go wrong with the Wheatstone's bridge, there is still the means of applying the direct insulation test, by simply removing the plugs P^1 and P^2 and inserting the plug P, when the current escaping through any leak will be at once indicated on the galvanometer G, the deflection of which will under such circumstances be largely increased.

The resistance coils R^1 are arranged, in connection with the galvanometer G^1 , to regulate the potential of the battery B, in the same manner as the resistance coils R, and galvanometer

OTHER LONG CABLES.





G^3 (Fig. A), are used for regulating the potential of the battery B in the shore arrangement. Battery B^1 (Fig. B) is used, in connection with the inverting keys attached thereto, for speaking to the shore: by pressing one or other of the keys, the potential of B^1 is added to or subtracted from that of B , so as to alter the charge in the cable.

It is necessary to render the galvanometer G (Fig. B) extremely sensitive when the insulation test is made, in order to ensure as fine a balance as possible in ascertaining that insulation; whereas when signals are to be received by it, its sensitiveness has to be reduced to keep the vibrations of the spot of light within certain limits; for this purpose it is supplied with a shunt, as shown in the diagram. Between every letter the galvanometer G is rendered very sensitive, and an insulation reading taken; but practically the insulation test is never off, for if any considerable fault occur during the process of speaking, the shore end of the cable being always insulated, and that on board ship in connection, through the galvanometer and slides, with the battery, the leakage of the current will produce a very considerable change in the indications of the galvanometer G , a far greater change than could possibly be produced in transmitting the signals.

It will be perceived that during the whole process of submergence the shore end of the cable is always insulated, and the tests are never removed either for signalling or any other purpose: this continuity of the tests is the great advantage of the system.

The foregoing has been, in the main, condensed from the very excellent lectures given by Professor Fleeming Jenkin to the Royal Engineers at Chatham, and it describes the system adopted during the laying of the 1866 Cable.

Mr. Willoughby Smith explains that the slides and battery in connection with the electrometer in the shore arrangement were used at the request of Sir William Thomson, merely as an experiment. But no trustworthy results were obtained by the arrangement, and therefore during the laying of the French Atlantic, the slides and battery were not used on shore, but the electrometer was permanently connected between the end of the

cable conductor and the earth, as a check on the condenser system for obtaining the potential of the line. In all the long cables laid since the French Atlantic, the condenser system *pure and simple*, without the electrometer, has been adopted with very satisfactory results.

METHODS OF WORKING CABLES, AND SPEED OF SIGNALLING.

513. The speed of working is determined by the time required to cause a sufficient variation of current at the distant end to affect the receiving instrument.

When a signal is sent through a cable, the current must complete its inductive action upon each successive portion of the outer coating before it can pass on to the next; as this occupies a sensible interval of time, a signal does not reach the end of a long cable till after a sensible interval. Some effect certainly is produced at the distant end as soon as the current is applied, but it is very feeble; the current gradually gains force until it reaches its maximum, when it remains constant.

In cables similar except in length, the time occupied by the current received at the distant end in attaining a certain proportion of its maximum strength, varies as the square of the length of the cable.

514. When a current is sent from Valentia to Newfoundland no effect is produced on the most delicate instrument for two-tenths of a second. After four-tenths of a second the current has attained about 7 per cent. of its maximum strength, and it is not till after three seconds that it gains its full strength and flows uniformly. When the battery contact is broken the current dies away gradually.

515. When signals are made on a Morse instrument a signal does not commence until the current has attained sufficient strength to act upon the electro-magnet, nor does it cease until

its force has diminished sufficiently to release the armature, so that a considerable difference of potential must be produced at the distant end of the cable; not only so—the wave must also rise above and fall below a certain fixed datum line.

The effect of induction, therefore, is, firstly, to retard the production of a signal, and secondly, to prolong it after the contact with the battery has been broken. If the cable is not put to earth at the battery end of the circuit between each signal, the effect of prolongation is at its maximum, for the charge can only escape at the receiving instrument. In this case, when dashes are sent, as shown by the upper of the two lines, a continuous line is produced; commencing a little late, thus—

— — —
—————

When an earth contact is made at the sending end after each signal, so that the charge can escape at both ends, the prolongation is less, and the received mark shorter. The three dashes will then appear thus—

— — —
—————

And if a reversed current is sent after each signal, so as to neutralize a portion of the charge remaining in the cable, by electricity of the opposite sign, the prolongation is still less.

— — —
—————

The retardation or loss of time in the passage of the current is the same in each case, although the speed of signalling is greatest in the last.

The effect is best shown by using a Bain apparatus to receive the signals. The line is then seen to commence with a point, gradually widening out till the wave attains its maximum, then maintaining an even width, and gradually tapering off, after battery contact is broken, until the current has become too weak to decompose the solution.

If a looped cable or artificial cable be available, the Bain may be fitted with two pens, one placed in a local circuit so as to show the actual duration of the battery contacts, the other at the receiving end of the cable. The first will produce the upper line of the illustrations, the second the lower line. The signals of the upper line will commence and cease abruptly, those of the second line will swell and diminish. But if a Morse be used as the receiving apparatus, the signals will resemble those shown in the text, because it cannot register the gradual increase and fall of the current.

516. It will be found by experiment with the Bain that the order of sequence of long and short signals affects their legibility, and that a succession of dots can be registered much more rapidly than mixed dashes and dots, because the longer duration of the battery contact in a dash charges the cable higher than the shorter contacts in dots, and therefore a longer time is required for the discharge.

517. But an instrument capable of showing each small variation of current, whatever be its absolute strength, will render signalling much more rapid than one in which the current must rise and fall above and below a fixed amount.

The reflecting galvanometer, when arranged for the purpose, fulfils this condition; the spot of light follows each small increase or diminution of current irrespective of the actual change in the cable, and can be read, however far it may wander from zero, provided only the light is kept on the scale. It is not difficult to decipher the movements of the spot of light even if it wanders over a field of several inches. The first dot moves the spot a long distance, the light moves slightly towards zero in the interval between the signals, the second dot does not produce as large a deviation as the first, but sends the spot only a little further, a third produces less effect still, but is legible. The actual method of signalling is by reversals, as in the single needle code, where movements to the right represent dashes, those to the left dots, but the long and short signals of the Morse code can be given also.

Suppose a needle carrying a mirror is placed in circuit, and that a difference of 20° in the strength of the current is required

to move the Morse, the Morse signals then will not be legible unless the needle moves 20° ; but mirror signals will be legible whether the needle moves 1° or 20° ; and, even though the cable may not have been fully discharged after preceding signals, so that the needle remains deflected even to 19° , yet if the next signal produce a variation of but 1° and moves the needle from 19° to 20° , the signal will be legible. Signals can be read anywhere between zero and 20° , while to produce a signal on the Morse the variation must be sufficiently large to move the needle 19° to zero and back again to the 20th degree. The mirror is merely a very sensitive single needle whose movements are magnified. The following diagram shows the shape of the wave under the two systems for the letter V.

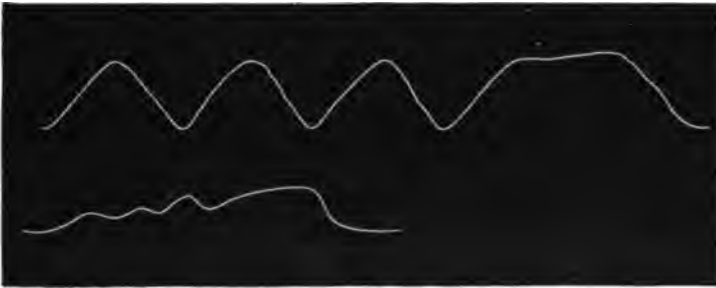


FIG. 126.

But there are methods by which the prolongation of the current can be decreased sufficiently to enable cables of 300 or even of 400 miles to be worked on the Morse system.

The double current system (410) increases speed.

518. The cables between England and Holland, and England and Hanover, are worked by the Morse with reversed currents. The signals are produced by the positive current, and the negative current is applied in the interval between the signals to discharge the cable. But this negative current, if in excess, charges the cable negatively, and must be discharged by the following positive current before the next signal can be recorded. It is therefore necessary to arrange that the negative shall be

only just sufficient to *compensate* or neutralize the positive; and it is found that the former should have about two-thirds the tension of the latter.

The ordinary hand-switch for changing the line wire from the key to the receiver cannot be used, because, to conform to the Continental practice, it is required that the clerks shall be able to *stop* one another during the slightest pause.

An automatic switch, technically called a *Zinc-sender* (Fig. 127), is employed. It consists of any polarized relay—Siemens', for instance—provided with two contact screws, the contact bar A has rather a wide play, and is fitted with a spring to lengthen the time of contact on the zinc side. The coils have a resistance at least equal to that of the line and receiving instrument; and the apparatus is connected as in Fig. 127.

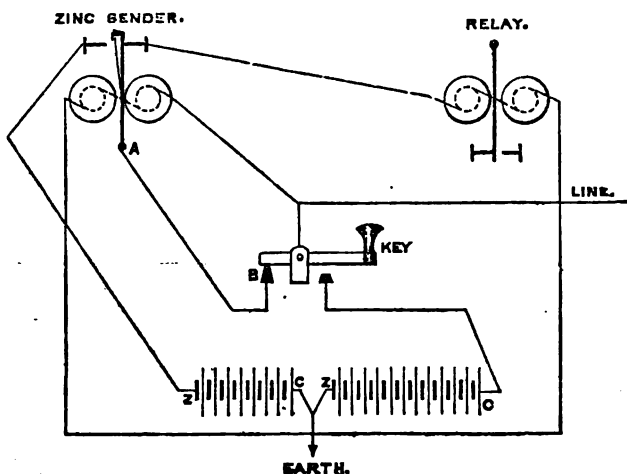


FIG. 127.

When the key is depressed, the copper or marking current divides between the coils of the zinc-sender and the line wire, moving the bar A from the screw connected with the receiving relay to that connected with the zinc, thus joining the back stop B of the key with the zinc battery. When the key is released, the zinc current divides in like manner between the

line and the coils of the zinc-sender, the one portion discharging the line, the other bringing the bar back from the zinc contact to the position for receiving signals from the distant station.

The contact bar A should be so adjusted as to be sufficiently attracted to the receiving side not to be acted on by the current from the distant station, or to be moved by the shaking of the table; and it should also *stick* sufficiently on the zinc side to remain there when the key is released until the key touches the back stop B, so as to permit the zinc to flow to line until the spring attached to the bar A has left the zinc-contact screw. The electro-magnet opposes for an instant the passage of the current, and therefore a larger proportion of current passes to line when a dot is sent than in the case of a dash. The deviation to earth assists in some measure in discharging the line.

Where this system is employed it is important that the resistance of the land lines connected to a cable, as well as that of the batteries and instruments, should be as small as possible, for the effect of adding resistance to either end of a cable is both to retard and weaken the signals. The effect of a given exterior resistance is greatest when it is equally distributed at either end, and least when placed at the receiving end of the cable.

519. Compensation is more easily effected by automatic than by hand signalling, as the relative duration and strength of the currents must be accurately apportioned in order to produce the best effect, and this can only be done by mechanical means. Some of these means will be described in the chapter on automatic systems.

A mechanical arrangement was designed by Varley for the Atlantic cables, called the *curb-key*. It was arranged to send five currents, of the following respective durations and signs:— $+100 - 156 + 80 - 32.5 + 26$, the resultant of which was a short positive signal, of a strength equal to one per cent. of that current which the battery would have produced if placed permanently in circuit; the second current was stronger than the first, in order that it might act as rapidly as possible.

However, the method about to be described, by which all the

longest cables are worked, has shown that with a very delicate receiving instrument no compensation is necessary.

520. *Method of working the Atlantic and other long cables.*—The signalling apparatus, as arranged by Mr. Willoughby Smith, and now in use on the cables laid between England, America, and India, consists of the following parts:—

(1.) A very sensitive mirror galvanometer of simple construction, and of a resistance of about 2,000 ohms: the spot of light is thrown from the mirror on a shaded screen. A movement of the spot of light to the left indicates a dot of the Morse alphabet, a movement to the right a dash, as in the single-needle code. These signals are produced by reversing the currents at the sending end by means of

(2.) An ordinary double sending-key like that of a single-needle; and

(3.) A battery composed of a small number of the cells known as Minotto's.

As the receiving apparatus is extremely sensitive, it is important to avoid the disturbing effect of earth currents (197), and for this purpose a *condenser*, having a capacity equal to that of 50 knots of the cable, is placed between the cable and the *receiving* instrument, the sending-key being connected directly to the cable. The condenser is not inserted to increase the *speed* of signalling; in fact it slightly retards it; but it very materially assists in obviating interferences by earth currents; it also tends to limit the space over which the light travels.

It has already been shown that when one plate, or a series of plates of a condenser is charged, the other being to earth, an equal quantity of electricity of the same sign leaves the opposite plate, returning when the charge is removed or reversed; and that if a galvanometer be placed between the second plate and the earth, it will be deflected for an instant by the passing of the electricity.

As the signals are thus given by short impulses, it is found occasionally necessary to introduce resistance into the circuit, to prevent too violent an action, or, as it were, to lengthen out the impulse. On long cables this is not necessary.

The weight of the mirror and magnet together is but three

grains ; a dead beat is obtained by using a very short suspending fibre, about $\frac{1}{16}$ inch, and a powerful directing magnet (125). The maximum speed is 22 words, or 110 letters a minute, on a cable 1,896 knots in length.

521. It has been proposed to use a modification of the induction coil (175), with a long fine primary, and a short, stout, secondary wire, instead of the condenser. The currents from the cable are made to pass through the fine primary wire, and the mirror is placed in the secondary circuit.

522. *Thomson's Recorder*.—The object of this apparatus is to register signals similar to those of the reflecting galvanometer upon a paper ribbon. In it the coil is moveable and the magnet is fixed. A light coil of very fine wire is suspended between the poles of a powerful horse-shoe magnet, in front of the coil is placed an insulated vessel filled with common ink into which a syphon of extremely thin glass dips ; the end of the syphon is bent horizontally and faces the paper ribbon ; it is so arranged as to be free to move in a direction at right angles to the length of the paper.

Consequently, if the ink is caused to issue from the syphon with sufficient force, and the syphon itself is moved from side to side, it will trace lines upon the paper.

If single-needle signals are sent through the circuit, the coil moves from side to side and moves the syphon by means of a thread connecting the two, and if the ribbon is caused to travel onwards, the movements of the coil will be recorded on the paper.

The spirting of the ink is necessary for the purpose of avoiding friction on the surface of the paper, and is effected by electrical repulsion, the ink vessel being charged to a high potential by means of a *doubler* driven by an electro-magnetic engine.



FIG. 128.

Fig. 128 is a fac-simile of the writing of the recorder.

The embarrassment caused by induction is felt on very short cables, and even on suspended wires, if the speed of signalling is proportionately increased; for at a speed of 60 words the effect begins to show itself on a land line of 200 miles. This question will be further considered in the chapter on Automatic Systems at the end of the volume.

523. *Methods of calculating speed.*—If we possess trustworthy data of the dimensions and speed of any existing cable, we may calculate those of any other, or construct a cable of any required working capacity.

But it must be premised, that in all calculations of speed it is supposed that the cables which are to be compared are worked precisely in the same manner; that is to say, if other things are equal, the relative speeds will be those given by the formula. This is a condition which never can be obtained, except by using a mechanical transmitter, and hence the speed calculated from trials upon some well-known good cable, the Malta-Alexandria, for instance, with a certain instrument and a certain clerk, frequently differ from the results obtained in practice, which in great measure depend upon the efficiency of the operator, and the skill with which the instruments are made and adjusted, as well as upon the system adopted.

For instance, the Morse is very much slower than the mirror, while the syphon recorder is almost as rapid as the mirror.

524. Jenkin¹ gives the following formula for the speed of mirror, based on a rate of 13 words per minute, through the French Atlantic cable, on which as many as 17 words have occasionally been sent.

Speed by mirror in words per minute—

$$= 0.2325 w \frac{\text{Log. } (70.4 w + 480 w) - \text{log. } 64 w}{L^2} \times 10^6$$

for percha, where w is the weight per knot of the copper and w the weight of the percha of the cable, and L its length in knots.

¹ Text-books of Science. "Electricity," p. 338.

525. *To find the speed of a cable whose dimensions are given from the known speed of another cable whose materials are similar but whose dimensions are different.*—Let it be required to calculate the speed, s , of 1,245 knots of the Persian Gulf cable, from the speed of the first Malta-Alexandria, which is said to have been 6 words through 1,000 knots.

In the former cable $d = 110$, $\log. \frac{D}{d} = \cdot 5383$, and $l = 1245$;

in the latter $d = 153$, $\log. \frac{D}{d} = \cdot 4808$, $l = 1000$, and $s = 6$.

Then by (4) page 277—

$$s : s :: 1000^2 \times 110^2 \times \cdot 5383 : 1245^2 \times 153^2 \times \cdot 4808 = 2 \cdot 24,$$

the calculated speed of 1,245 knots of the Persian Gulf cable, when worked in a similar manner to the Malta-Alexandria.

526. *To calculate the proper proportions of the core of a cable to provide for the transmission of a certain given number of words per minute.*—The Malta-Alexandria cable is assumed for calculation to have given 6 words per minute by Morse through 1,000 knots. It actually gave 17 words through 597 knots, but by (2) page 227

$$1000^2 : 597^2 :: 17 : 6.$$

Suppose that it is desired to construct a cable of 500 knots in length which shall give 10 words per minute by Morse. If we were to make use of the dimensions of the Malta-Alexandria cable, 500 miles would give us 24 words per minute, for

$$500^2 : 1000^2 :: 6 : 24.$$

We therefore can reduce the dimensions of the Malta-Alexandria core until we produce a cable of such dimensions that

$$L R I = L'^2 R' I',$$

where the one side of the equation equals the dimensions of the Malta-Alexandria cable, and the other side those of the required cable.

In the above equation it is evident that $L = 775$, because

$$775^2 : 1000^2 :: 6 : 10$$

and therefore 775 knots is the length of the Malta-Alexandria core, which would give 10 words per minute.

And as $\frac{1}{RI}$, or the reciprocal of the product of the resistance and inductive capacity of the Malta-Alexandria cable is 129,¹ the equation becomes.

$$\frac{775^2}{129} = \frac{500^2}{x}, \text{ or } 775^2 :: 500^2 :: 129 : x;$$

therefore $x = .054 = \frac{1}{RI}$ for the required cable, and $RI = 18.5$.

In the Atlantic Cable the ratio $\frac{D}{d}$ is 3.18 and its log. .502, but if we made the ratio of the outside to the inside diameter of our cable 3.16, the logarithm of this or

$$\log. \frac{D}{d} = .500$$

$$\text{and } \frac{1}{\log. \frac{D}{d}} = 2.$$

Again, as $RI = 18.5$,

$R = 9.25$, by substituting the above value of I .

Therefore the conductor of our cable must be a stranded wire whose resistance equals 9.25 ohms per knot.

Now, this would be a strand of .102 in. diameter, and therefore we must make the diameter of our insulating covering such that

$$\log. \frac{D}{d} \text{ or } \log. \frac{D}{.102} = 500.$$

¹ The following are the dimensions of the Malta-Alexandria cable, from whence $\frac{1}{RI} = .129$ is derived.

Outside diameter of core = .457 = D
Diameter of conductor = .162 = d

Ratio $\frac{D}{d}$	$\log. \frac{D}{d}$	$\frac{1}{\log. \frac{D}{d}}$	Resistance of conductor (R)	RI	$\frac{1}{RI}$
2.82	.4502	2.222	3.49	7.75	.129

D therefore is .322 in. in diameter, so that a cable 500 knots in length, whose conductor measures .102 in. diameter and gives a resistance of 9.25 ohms per knot, and whose insulating coating of gutta-percha measures .322 diameter, will give us a speed of 10 words per minute, if worked in the same manner as the Malta-Alexandria. (*Preece.*)

These data are taken from the original Malta-Alexandria cable, the $\log. \frac{D}{d}$ of which is given by Clark and Sabine¹ as 0.4809. The speed by Morse is given above as 6 words through 1000 knots, but the speed of the present cable worked by mirror is 19 words through 925 knots, and the $\log. \frac{D}{d}$ is 0.5107.

527. The determination of the relative speed of cables by the number of words per minute which can be sent by hand is very unsatisfactory, because so much depends upon the individual skill of the *operator* and the perfection of the apparatus.

It has therefore been proposed to use an automatic transmitter to produce the signals, or to calculate the *speed of a wave* by mechanical means. For the latter purpose Siemens uses a *wippe*, and Varley a rotating commutator. In the latter, two brass discs A and B are placed upon the same axis, but are insulated from it. Each disc is also divided into two insulated halves, the divisions being exactly in the same line. The halves of A are connected to the two poles of a battery, the halves of B to the two terminals of a galvanometer, wound with a thick wire, and having somewhat heavy astatic needles delicately suspended. Contact springs are fixed on opposite sides of each disc, pressing upon its edge; those on one side each disc are connected to earth, those on the other to the two ends of the cable. Thus when the discs are made to revolve, A sends alternately positive and negative currents into the cable, while B reverses the connections of the galvanometer at the distant end (B) of the cable at the same instant the current is reversed at A. This being so, if a short wire is used to connect A and B, the speed of the current will be infinite, and the needle will be de-

¹ Electrical Tables and Formulae

flected uniformly to the same side, because the force acts always in the same direction. But if a condenser or cable be placed between A and B (the current will be retarded, and will occupy a sensible time in passing through the cable from A to B), it will not be reversed at the receiving end, B, at the same moment that it is reversed at the sending end, A, so that more current will flow through the galvanometer in one direction than in the other, and the needle being acted on by two opposite but unequal forces, will take up a smaller angle of deflection, obeying the greater of the two.

But by increasing the speed of the machine until the wave is bisected—that is, until the galvanometer connections are reversed at the moment the received current has attained half its duration—the galvanometer will receive, *after* it is reversed, a current equal in strength to, and of the same name as, that which passed through it *before* it was reversed, but it will pass in the *opposite direction*, so that the needle being acted on equally in both directions, will remain steady.

The longer the wave the greater the retardation, and consequently the slower the rate of rotation to measure it.

The law of the squares (461) can easily be verified by this apparatus.

528. *Difference in speed between a coiled and a straight cable.*—It has been thought that the induction of one coil upon another retards transmission through a coiled cable. To prove if this be so, experiments were made during the manufacture of the Dublin cable in 1870. The highest speed at which *perfect* Morse signals could be produced with the Wheatstone automatic apparatus, was ascertained while the cable was coiled in water in the tanks, and was found to be 45·8 words per minute through 52 knots. After the cable had been laid, a similar experiment was made by the same observers, and with the same apparatus, The speed was *increased* to 50·3 words through 57·9 knots, when the cable was straight instead of being coiled. It was also ascertained that with this apparatus, speed varied sensibly as the length and not as the square of the length of the cable; defining speed as the number of *perfect* Morse signals which it was possible to obtain in a given time.

MISCELLANEOUS NOTES.

529. *Extra current.*—The influence of the *extra current* from a coil, and more particularly from a coil containing iron, as an electro-magnet, in retarding and mutilating telegraph signals, should be particularly taken into account in telegraphic arrangements. The disturbing effect of electro-magnets is more particularly evident when they are introduced in the circuit at or near the sending end of a submarine cable, on account of the comparatively large amount of current required for the first portion of each signal; the effect is, to shorten a dot considerably, or to entirely prevent its transmission, for until the iron has become magnetized no signal will be sent. The effect on a longer signal than a dot will be to shorten it, but to a less extent. When a dash or several dots in succession are sent through the coils, the iron retaining a portion of its magnetism after each break, will have a different effect on each succeeding current, so that compensation is almost impossible, and the signals at the receiving station will exhibit the greatest irregularity. Any cause tending to alter the magnetic condition of the iron will cause a corresponding variation in its disturbing influence upon signals, so that an armature placed before the poles of an electro-magnet, or arranged to be attracted by it, as in a relay, will increase the interfering effect; and the amount of this interference will vary with the distance of the armature, the maximum disturbing influence being produced when the armature is in contact with the cores, and diminishing rapidly according to the distance to which it is removed from them. The greater the mass of iron in the cores, the heavier the armature, and the more sluggishly it moves towards the electro-magnet, the greater the effect upon the signals.

A polarized relay, such as Siemens', has less effect than an ordinary electro-magnet, because the variation of magnetism is less and the extra current feebler. The less the resistance of the wire surrounding the iron or the shorter the coils of a galvanometer, the smaller the disturbing effect. A galvanometer of

many turns has a sensible effect if introduced at the sending end of a circuit, while a Morse wound with No. 30 wire, and of comparatively few turns, has but a slight effect. Probably if the coils were shunted so as to afford a path for the extra currents, the disturbing effect would be lessened.

Several Morse instruments introduced into the same circuit will interfere to some extent with each other, independently of any retardation consequent upon the length or other conditions of the conductor, and the armatures will not be attracted at the same instant. This effect is felt even on a suspended wire.

530. *Difference in effect of + and - currents on insulation.*—When the insulation of a cable is defective, better signals can be obtained when working with a positive than with a negative current, as it appears to seal up the fault. But it slowly, but surely, eats away the conductor, and in time causes it to fail suddenly. On the other hand, a negative current tends to preserve the conductor, and although signals will not be so good, the cable will remain unharmed.

531. *Note on the Atlantic cables.*—Earth currents are perfectly prevented when condensers are placed at both ends of a cable, and when two cables are looped so as to form a metallic circuit insulated from earth.

When a condenser is used at the receiving end only, the earth current affects the mirror if the key switch is turned quickly, but this can be prevented by shunting the condenser.

The single cable with two or even with one condenser is more rapid than the two cables looped, for the second cable discharges itself more slowly than a condenser, because of its resistance.

532. *Note on speed in buried wires.*—(a.) When two were looped so as to be perfectly insulated from earth, speed was 60.

(b.) When two were looped, one pole of battery to earth at sending station, the other wire to earth at the same station, and the instrument insulated at the receiving station, speed was 80.

(c.) With a single wire worked in the ordinary way, a speed higher than 80 was obtained.

(d.) No increase in speed was obtained by doubling the conductivity in (a) or (b) by using two wires instead of one; and

(e.) When fourteen wires were connected side by side at both stations, and worked in the ordinary way, as in (c), speed was *less* than with a single wire, because capacity was increased in a higher ratio than conductivity.

533. *Application of the principle of compound interest to calculations of the relation of temperature to resistance.*—If the resistance of a metallic wire be increased at a certain rate per cent. by a rise of one degree of temperature, it will be increased by the next degree of rise at the same rate per cent. calculated upon the *new* resistance, not upon the original resistance. Thus if the original resistance at the commencement of the experiment represent the principal; the rate of increase, the rate of interest; and the new resistance after the temperature has been raised one degree, the amount or sum of principal and interest after the first year; the increase due to the elevation of temperature a second degree will be equivalent to the interest for one year on the new principal, and so on. Conversely, the diminution of resistance in a wire caused by a fall of temperature, and the increased leakage (diminution of resistance) of the insulator of a core caused by a rise of temperature, obey the law of discount in money.

This law enables us to construct tables for the reduction of readings of resistance or insulation to the standard of 75 degrees, and for the calculation of the reading at any temperature from a test made at any other.

To construct a table for copper (Table XIII.), first find by trial the resistance of a coil of known length and diameter, at two temperatures, as widely apart as possible.

Let R be the resistance at the higher temperature,

r that at the lower temperature,

n the difference in degrees between the two,

and p one unit of resistance (one ohm), plus the increase of resistance due to a rise of one degree Fahrenheit; that is to say, the sum or amount of principal and interest for one year.

Then
$$(1) \log. p = \frac{\log. R - \log. r}{n}$$

From this the resistance r' at any other higher temperature may be found by

$$(2) \log. r' = \log. r + n' (\log. p)$$

where n' is the difference in degrees between r and r' , or between the lower of the two former temperatures and that whose corresponding resistance is sought. For example, having found by experiment that the resistance of a knot of pure copper wire is

$$\begin{array}{rcl} 1091.22 \text{ ohms at } 32^\circ \text{ Fahrenheit} \\ 1156.03 \quad \quad \quad \text{,,} \quad 60^\circ \quad \quad \quad \text{,,} \end{array}$$

we require to find its resistance at the standard temperature, 75° Fahrenheit.

$$\text{Here } R = 1156.03$$

$$r = 1091.22$$

$$n = 28^\circ$$

and we have by (1)

$$\frac{\log. 1156.03 - \log. 1091.22}{28} = .0008950 = \log. p.$$

Again, as $n' = 75 - 32 = 43^\circ$, by (2)

$$\log. r' = \log. 1091.22 + 43^\circ (.0008950) = \log. 1192.33.$$

1192.33 ohms is therefore the resistance at 75° Fahrenheit.

To form a table of the resistance of the wire for each degree, $\log. p$ is determined by (1). Then taking $\log. r$ as the log. of the resistance at the lowest temperature, $\log. r + \log. p =$ the log. of the resistance at the first degree of increased temperature, and again by adding $\log. p$ to the log. of this new resistance, we obtain the log. of the resistance at the second degree, and so on. From the table, when formed, the resistance of any coil may be found by proportion.

But it will be found by an inspection of formula 2, that the log. of the difference in resistance at any two temperatures is always $\log. p$ multiplied by the difference of temperature, or that if we want the resistance (r') due to a rise of 10° we may say—

$$\log. r' = 10 \log. p + \log. r.$$

Therefore, if we multiply $\log. p$ by 1, 2, 3, 4, and so on, we obtain a series of logs., the numbers corresponding to which

form a new series of co-efficients by which the resistance of any copper wire may be multiplied to find its new resistance at an increase in temperature of 1, 2, 3, or 4 degrees, and their reciprocals will be applicable to a scale of decreasing temperature.

For example, the resistance at 32° was found to be 1091·22,

$$\begin{array}{rcl} \text{The log. of which is} & . & . & . & 3\cdot0379124 \\ \text{Log. } p \text{ is} & . & . & . & \cdot0008950 \\ \text{The sum is} & . & . & . & \hline & & & & 3\cdot0388074 \end{array}$$

which is the log. of 1093·47, the resistance at 33°, and as the log. of

$$\begin{array}{rcl} \text{The resistance at 33° is} & . & . & . & 3\cdot0388074 \\ \text{By adding log. } p & . & . & . & \cdot0008950 \\ \text{We obtain} & . & . & . & \hline & & & & 3\cdot0397024 \end{array}$$

the log. of 1095·72, the resistance at 34°.

For example, the resistance of our coil at 32° is 1091·22, and log. p is 000·8950. The co-efficient for 28°, the difference between 32° and 60°, is the number corresponding to 28, log. p , or 1·0594, and therefore $1091\cdot22 \dots 1\cdot0594 = 1156\cdot03$, the resistance at 60°.

Again, to apply the co-efficient to the determination of temperature from resistance, we know that when the resistance of our coil is 1091·22 the temperature is 32°, and if on making a second test we find the resistance is 1156·03, and desire to know the temperature, we say $\frac{1156\cdot03}{1091\cdot22} = 1\cdot0594$, which, on reference to the table of co-efficients (Table XIII.), we find opposite a difference in temperature of 28 degrees. The temperature is therefore $32 + 28 = 60^\circ$. (*Preece.*)

534. *Application of the principle of compound interest to the calculation of fall of charge.*—The law explained in the preceding paragraph governs the fall of potential in a cable when charged and left insulated, so that the time required for the charge to fall to one-half or any other fraction may be obtained from the fall observed during a given interval. This is very convenient when testing materials of high insulating powers, which lose their charge very slowly.

535. The following table, supplied by Mr. Latimer Clark, shows the rate of fall of potential in the Atlantic cable of 1866, when charged and left insulated.

ELECTROMETER TEST OF 1866 ATLANTIC CABLE, TAKEN SEPTEMBER 11TH,
1866—100 CELLS NEGATIVE.

Percentage of Charge remaining.	Observed Time of Falling.	Percentage of Charge remaining.	Observed Time of Falling.
	min. sec.		min. sec.
100	0 0	73	25 19
97	2 52	72	26 23
96	3 29	71	27 17
94	4 57	70	28 31
93	5 39	69	29 45
92	6 21	68	31 6
91	7 10	67	32 29
90	7 41	66	33 46
89	8 41	65	35 27
88	9 33	64	37 3
87	10 25	63	38 42
86	11 17	62	40 36
85	12 18	61	42 6
84	13 26	60	43 49
83	14 20	59	45 45
82	15 31	58	47 45
81	16 29	57	50 10
80	17 26	56	52 0
79	18 28	55	54 13
78	19 32	54	56 20
77	20 37	53	58 11
76	21 36	52	60 50
75	22 43	51	63 21
74	23 55	50	66 41

The observations were made in the following manner:—A rheostat, consisting of 100 coils, each of 1,000 ohms' resistance, connects the poles of a battery of 150 cells, the copper of which is put to earth. The potential in these coils will be negative, rising from the end connected to the zinc to zero at the opposite extremity. A wire is arranged to slide from end to end of the rheostat, so as to take up the potential of the point at which it may be placed. The cable is first charged by connecting it to the zinc of the battery; it is then removed and placed in contact with one side of a Thomson electrometer; the

wire is connected to the opposite side of the electrometer, and made to slide from point to point along the rheostat until it balances the declining potential of the cable, when its position on the slide shows the charge remaining in the cable.

From this table it will be seen that whatever percentage of the charge escapes during the first minute, the same percentage of the charge, *then remaining in the cable*, will escape during the second minute, and so on; and the charges, if plotted out as ordinates and abscissæ, form a logarithmic curve.

536. The simplest way to show the mathematical law of the fall of charge from full to half tension is to consider it in reverse order, that is, to calculate the time it will take to *double* a charge accumulating at a regular known increment. This is simply an application of the principle of compound interest.

Thus, if C be the charge upon a cable, increasing by the compound ratio r , it is required to know the time that C will take to become $2C$. It is evident by the common rule of compound interest that at the end of the first unit of time, C will become $C + Cr = C(1 + r)$, in the second unit of time $= C(1 + r)^2$, and in n units of time $= C(1 + r)^n$.

$$\begin{aligned} \text{But} \quad C(1 + r)^n &= 2C, \\ \text{therefore} \quad (1 + r)^n &= 2, \end{aligned}$$

which when r is known, will give us the units of time t that any cable will take to rise from half to full charge, and, *vice versa*, to fall from full to half charge.

We find from Clark's table that in the case of the Atlantic cable, r was 3 per cent. $= \frac{3}{100} = .03$, in the unit of time 2.87 minutes.

$$\begin{aligned} \text{Therefore} \quad 1 + r &= 1.03 \\ \text{and} \quad 1.03^n &= 2 \\ \text{therefore} \quad n \log 1.03 &= \log 2. \\ n &= \frac{.301}{.013} = 23.15,^1 \end{aligned}$$

¹ .301 is the log. of 2, and is therefore used in calculating the fall to half-charge. If any other fraction of the charge be required, the log. corresponding to that fraction is used instead of the log. of 2.

.013 is the approximate log. of 1.03.

which multiplied by the unit of time, 2·87 minutes, gives $23·15 \times 2·87 = 66·44$, or 66 minutes 26 seconds.

Clark's observation gave the actual time as 66 min. 41 sec.

The formula is more simply given thus :—

$$nt = \frac{·301}{\log. (1 + r)}$$

where r = percentage of fall in n units of time t , t may be omitted if we make the unit of time one minute. The observation will not be so correct if a larger unit of time be taken.

Having, therefore, charged a cable and read the electrometer, it is only necessary to allow it to leak one minute, take a second reading, and then by comparing the difference of charge, to obtain the percentage of fall in the unit of time, and by means of the above formula to calculate the time it would take to fall to half-charge. (*Preece.*)

537. *The law of Shunts.*—It has been shown in par. 242, that a current divides between two conductors in inverse proportion to their resistances. A *shunt* is a resistance placed across the

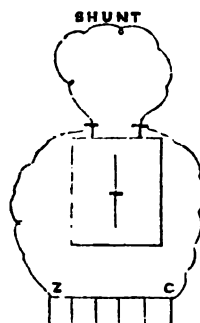


FIG. 129.

two terminals of a galvanometer or electro-magnet to reduce its sensibility, by diverting a portion of the current passing through its coils (Fig. 113). If the shunt be exactly equal in resistance to the galvanometer, the current will divide equally, and the deflection will be exactly one-half of what it was without the addition of the shunt. If the shunt be one-half the resistance of the galvanometer, two parts will flow through the former and

one through the latter; the deflection will then be one-third and must be multiplied by three, to compare it with the deflection given by a wire tested without the shunt, and so on.

Let e be the whole force of the current, e' the portion of the current which passes through the galvanometer. Then $e - e'$ will be the portion passing through the shunt.

Let g and s be the respective resistances of the galvanometer and shunt, then

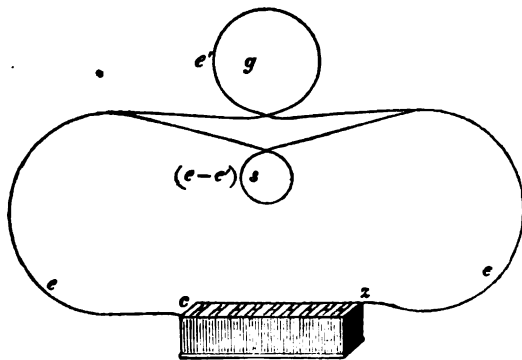


FIG. 130.

$$g : s :: e - e' : e'$$

whence $\frac{e'}{e} = \frac{s}{g} + 1 = \frac{s}{g + s}$, being the proportion of the battery current passing through the galvanometer, the reciprocal of which, $\frac{g + s}{s}$, or $\frac{g}{s} + 1$, is the factor by which the indications of the shunted galvanometer must be multiplied, to render them equal to the indications of the same galvanometer without the shunt.

The rule for ascertaining the *resistance* of a shunt intended to reduce the sensibility of a galvanometer to *any required fractional part* n is

$$s = \frac{g}{n - 1}$$

as will at once be evident from an inspection of the following table of the shunts most often required.

TABLE.

Amount to which the deflection is to be reduced.	Resistance of shunt required.	Resistance of compensating wire.
To $\frac{1}{2}$	Equal to galvanometer.	Half of galvanometer.
„ $\frac{1}{3}$	$\frac{1}{2}$ of galvanometer.	$\frac{1}{3}$ of galvanometer.
„ $\frac{1}{4}$	$\frac{1}{3}$ „ „	$\frac{1}{4}$ „ „
„ $\frac{1}{5}$	$\frac{1}{4}$ „ „	$\frac{1}{5}$ „ „
„ $\frac{1}{10}$	$\frac{1}{9}$ „ „	$\frac{1}{10}$ „ „
„ $\frac{1}{100}$	$\frac{1}{99}$ „ „	$\frac{1}{100}$ „ „

538. *To find the resistance of a battery:—*

(1.) When the entire resistance of a circuit, including a galvanometer, is *doubled*, the deflection, which is proportional to the tension of the battery divided by the resistance of the circuit, will be *halved*. Connect a sine or a tangent galvanometer of known resistance on short circuit with the battery to be measured. Reduce the sensitiveness of the galvanometer, if necessary, by a shunt, and note the sine or tangent of the deflection. Add extra resistance until the sine or tangent of the deflection is exactly halved, showing that the *total* resistance of the circuit has been doubled. Deduct the resistance of the galvanometer and connections (allowing for the shunt) from the *extra resistance added*, the remainder will be the resistance of the battery.

For instance, if the galvanometer and connections have a resistance of 50 ohms, and the addition of 70 ohms be required to halve the sine or tangent of the deflection, the battery resistance will be 20 ohms.

(2.) Place the battery in circuit with a galvanometer whose resistance, g , is known, and a set of resistance coils; adjust the coils till a suitable deflection is obtained. Let this resistance be R .

Then shunt the battery by a wire whose resistance is s , and

decrease the resistance R until the deflection is the same as before. Call this new resistance r , then

$$\text{Battery resistance} = s \frac{R - r}{g + r}$$

(3.) Make the battery the arm B of the Wheatstone bridge, let the arms C and D be fixed resistances and A the variable resistance; connect the points where A and C and B and D join by a thick wire including a key by which the connection may be made and broken, and let the galvanometer occupy its ordinary position.

Adjust the resistance in A until the making and breaking contact by the key does not alter the deflection of the needle;

$$\text{then the battery resistance} = \frac{D A}{C}.$$

This method is not affected by variations in the force of the battery, and is therefore the most accurate.

539. *To find the resistance of a galvanometer*, without the aid of a second instrument.—(1.) Place it in circuit with a set of resistance coils and shunt the galvanometer so as to obtain a suitable deflection. Next alter the shunt and adjust the resistance coils till the deflection is the same as before.

Let R and r , S and s , be the respective resistances of the coils and of the shunt in the two operations, then galvanometer

$$\text{resistance} = \frac{(R - r) S s}{R s - r S}.$$

(2.) Exchange the places of the battery and galvanometer in battery resistance test (3).

540. *To compare E, the electromotive force of batteries:—*

(1.) Connect the battery with a galvanometer, and introduce resistance until a deflection, say of 30° , is obtained. Introduce more resistance until the deflection is reduced to 25° , noting the length of wire required to produce the *diminution of 5°* .

The greater the electromotive force, the greater will be the resistance required to effect the diminution of 5° , and the comparative forces of batteries may be expressed by the number of units of resistance employed. (*De la Rive*, "Treatise on Electricity," vol. ii. p. 788.)

(2.) An approximate measurement may be obtained by placing a few cells, twelve or less, in circuit with a tangent or sine galvanometer, introducing so much resistance, 10,000 units or more, that the resistance of the batteries to be compared may be neglected. The sines or tangents of the deflections obtained will then express the relative electromotive forces. This method, however, is inferior to the former, as it does not admit of the reduction of the measurements to a fixed standard, or of the accurate comparison of measurements taken at different times.

(3.) A condenser may be charged from each battery and discharged through a galvanometer, as in taking a capacity test. The electromotive forces will be directly as the deflections observed.

541. FORMULA for the effective current on a wire having two faults, partial earth, or contact (234):—

Let E be the electromotive force of the battery;

R the resistance of the wire from the battery to the first fault;

r' that of the line wire between the faults;

r'' that of the wire from the second fault to the distant station, including the apparatus;

L the total circuit ($R + r' + r''$);

f' the first fault;

f'' the second fault;

The effective current

$$\frac{E f' f''}{R f'' (R + r'') + r'' f' (R + r') + R r' r'' + L f' f''}$$

Or in the case given in par. 227, p. 130, E being 1000,

$$\frac{1000 \times 20 \times 20}{50 \times 20 (20 + 80) + 80 \times 20 (50 + 20) + 50 \times 20 \times 80 + 100 \times 20 \times 20} = 2.4$$

542. On the graphical solution of problems based on Ohm's laws. —Since a current of electricity depends only on resistance and electromotive force, and varies with these two quantities in simple proportion, the one inversely and the other directly ($C = \frac{E}{R}$), we

have a very convenient method of representing graphically, by means of geometrical figures, the relations that exist between them.

If we measure resistances along a horizontal line, and electro-motive force or potential along a vertical line cut off between the point where it touches the circle of which one leg is the radius or base, and the other the hypotenuse of the right-angled triangle of which it forms the perpendicular.

Thus $\frac{A B}{A C}$ (Fig. 131) is the numerical, and the line A B the geometrical tangent of the angle A C B when A C is radius.

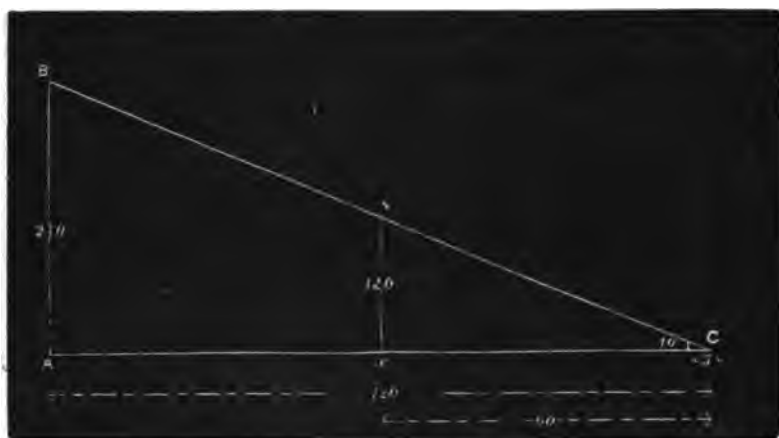


FIG. 131.

Let A C represent a resistance of 120 ohms, and A B an electro-motive force of 24 cells, then a line xy at any point of A C will represent the potential at that point. And since the ratios $\frac{A B}{A C} = \frac{x y}{C x}$, and therefore the angle A C B, are everywhere the same, we see that the current is the same at every point of its path at any given moment.

Let A C (Fig. 132) represent the internal resistance of one cell, C D the external resistance of the circuit, A B the electromotive force of one cell; then the tangent of the angle B D A represents

A A

the current. Add another cell, $E C$ will be the resistance and $E G$ the electromotive force of the two together, and the tangent of the angle $E D G$ will give us the current. Similarly, $F C, I C$, give the resistances, and $F H, I K$, the electromotive forces, of three and four cells; the tangents of the angles $F D H, I D K$, giving the currents. The ratios $\frac{I K}{I D}, \frac{F H}{F D}, \frac{E G}{E D}, \frac{A B}{A D}$ are the numerical tangents in each case; and if we take any length $D x$ as radius and describe the arc $x x'$, drawing the line $x y$ perpendicular

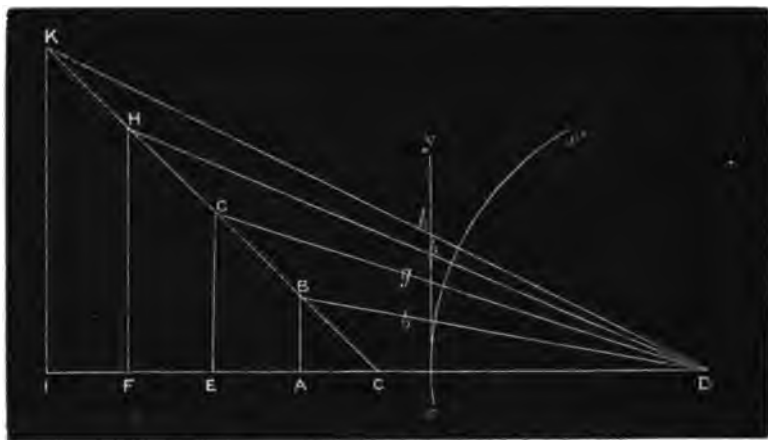


FIG. 132.

to $x D$, then $x b, x g, x h, x k$ will be the geometrical tangents, the ratios and the lines giving, in each case, the relative strengths of the currents from the different combinations. In this way we see that as we increase the electromotive force, so we increase the current when the external resistance is considerable.

Let now the external resistance be nothing; then the angle $A C B$ will give us the current from one cell, $E C G$ from two cells, $F C H$ from three cells, and $I C K$ from four cells, all these angles being the same. Thus as we add cells we do not disturb the angle $F C H$, which shows that the circuit from any number of cells on short circuit is the same as that from a single cell.

Thus taking the case of A (par. 87), the diagram Fig. 131 gives precisely the same result as is there worked out numerically. Case B can similarly be solved by Fig. 132. Here $L = CD$, and $E = IK$, and $R = IC$. If the lines xk, xg, xb , be measured, they will be found to be in the proportion $1.0 : .6 : .4$. In the same way, all the cases given in the subsequent paragraphs can easily be represented and solved graphically. (*Preece.*)

543. *Memoranda* :—

Ratio between circumference and diameter of a circle . .	3.1416
Ratio between area and diameter of a circle	.785
Specific gravity of pure copper (<i>Miller</i>)	8.921 to 8.952
" " cable copper (<i>W. Smith</i>)	8.899
" " iron (<i>Miller</i>)	7.884
" " percha (<i>Clarke</i>)	0.981

544. *Weight of Cable Cores.*—The following empirical data may be found sometimes useful for calculating the approximate weight of cores. 64 circular mils (thousandths of an inch) in sectional area of copper, 69 circ. mils of copper strand, 63 circ. mils of iron, 481 circ. mils of gutta-percha, or 401 circ. mils of Hooper's material, weigh one pound per knot. Hence $\frac{d^2}{54}$ gives the weight per knot of any solid copper conductor, and $\frac{d^2}{69}$ of any copper strand; and similarly, $\frac{D^2 - d^2}{401}$ gives the weight of Hooper's material, and $\frac{D^2 - d^2}{481}$ the weight of gutta-percha in any core; $\frac{d^2 n}{6789}$ gives the weight of iron in cwts. per knot (including lay) for any cable of n wires. (*Clark.*)

545. *The Morse Alphabet.*—The following system may be useful in learning the signals of the Morse and needle instruments :—

The Morse alphabet is formed by dots and dashes: in the needle alphabet the *dot* is represented by a movement to the *left*, the dash by a movement to the right.

The letters whose signals consist of dots or dashes only, are grouped together and represented by a sentence.

Each letter, consisting of dots and dashes combined, is repre-

sented by a word or sentence commencing with the letter itself, and made up of long and short syllables corresponding with the dots and dashes of the signal representing it. Thus, the letter D — — — one long and two short, may be represented by the word *Dōmīnle*.

THE MORSE CODE.

- (1.) Dots E - I -- S --- H ----
Earwigs infest summer houses.
- (2.) Dashes. T — M — — O — — — CH — — — —
Turnips make oxen cheerful.
- (3.) Dots and dashes.
- | | | |
|---|---------|------------------------|
| A | - — | ālārm |
| B | — — — — | beāutīfūllŷ |
| C | — — — — | cīrcūmstāntiāl |
| D | — — — | dōmīnle |
| F | — — — — | fīlbūstēr |
| G | — — — | glāssgrīndēr |
| J | — — — — | jāpān vārniśh |
| K | — — — | kīss mē quīck |
| L | — — — | lēgītīmāte |
| N | — — | nīmblē |
| P | — — — — | prōnoūnce plāinlŷ |
| Q | — — — — | quīck, quēnch thē fīre |
| R | — — — | rēcēivēr |
| U | — — — | ūnāttāched |
| V | — — — — | vānītŷ fāir |
| W | — — — | wē lōve plāy |
| X | — — — — | ēxcēllēnt bēer |
| Y | — — — — | yōu ālārm āll |
| Z | — — — — | zīnc bātteriŷ. |

Numerals.

1	— — — — —	6	— — — — —
2	— — — — —	7	— — — — —
3	— — — — —	8	— — — — —
4	— — — — —	9	— — — — —
5	— — — — —	0	— — — — —

Marks of Punctuation, &c.

Full stop	(.)	-----
{ Note of Interrogation }	(?)	-----
{ or Repeat . . }		
Hyphen	(-)	-----
{ Parenthesis . . . }	()	-----
{ P P on the Needle . }		
{ Inverted Commas . }	(" ")	-----
{ C C on the Needle . }		
Underline		-----
{ Begin another Line . }		
{ G Q on the Needle . }		-----
Bar of division	($\frac{1}{2}$ $\frac{1}{2}$)	-----
"DQ" must always be signalled		-----
and never		-----

Miscellaneous Signals.

Understand Message		-----
Correction or rub out		-----
{ End of Message . . }		
{ P Q on the Needle . }		-----
{ Wait }		
{ M Q on the Needle . }		-----
Cleared out and all right		-----
or		-----

546. *The Voltmeter*.—When two wires, connected with a battery, are placed a short distance apart in water containing a few drops of sulphuric acid, the water is decomposed. If the wires are terminated by small platinum plates,¹ the oxygen and hydrogen will rise in bubbles through the water; and as the amount of decomposition, and therefore the volume of gas produced, depends upon the quantity of electricity passing in a

¹ It is necessary to use platinum, as the oxygen combines with all oxidated metals.

given time, the volume of gas collected in a graduated glass tube in one minute is an accurate measure of the strength of the current.



Fig. 133.

547. *Preservation of Timber.*—The only effectual methods of preserving timber are the chemical processes, and as the price of larch has nearly doubled within the last few years, it has risen so nearly to the cost of chemically prepared inferior timber, such as Scotch fir and Baltic poles, that the chemical method has come largely into use.

If we can expel the fermentable sap from the tree, or by means of an antiseptic prevent its decomposition, we shall prevent the ulterior alteration of the woody fibre itself.

(1.) *Kyanising*, or steeping the timber in a solution of *bichloride of mercury* or *corrosive sublimate*, has not been extensively tried, because of its expense, and because it does not succeed unless the timber is dry. The poisonous nature of the salt is a very serious objection.

(2.) *Chloride of Zinc* has been used both in the same way as mercury, by simple immersion, and as the copper in Boucherie's process. It is said to wash out.

(3.) The following process was tried in Prussia, but without success. Sulphate of iron was injected into the wood, and the excess over and above that which entered into chemical combination with the albumen of the sap, was removed by a subsequent injection of chloride of barium. Iron seems rather to

destroy than to preserve wood; it is certainly destructive to oak.

Injection with chloride of calcium, common salt, sulphate of soda, and other salts has been tried without success.

It was thought that if holes were bored 2 or 3 feet into the pole from each end, filled with creosote and securely closed, the creosote would diffuse itself, and thus preserve the timber; this plan, however, has failed. Lateral penetration is very small, especially in heartwood.

548. *Boucherising* (or injection with sulphate of copper) and *creosoting* have been very successful, especially the latter.

The process of creosoting is too well known to need description. The method of boucherising may be described as follows:—A cistern is placed on a scaffold some twenty-four feet above the ground; a tube leads from the cistern to a horizontal pipe placed about a foot from the ground; from this latter pipe a series of flexible tubes branch out, each having a wooden disc on its end. The poles to be injected are laid on a low trestle, parallel and perpendicular to the main pipe, each butt being opposite a flexible tube; a thin slice is sawn off the butt, a circular indiarubber ring is placed along the edge, the disc attached to the tube is placed on the ring, and screwed tightly against it by the tenon bolts. This plate or disc, together with the ring, forms a water-tight chamber for the reception of the solution of sulphate of copper, communicating with the vertical pressure-pipe. The proportions employed in making the solution are—1 lb. of sulphate of copper to 5 gallons of water. It is usual to inject about 0.35 lb. of the sulphate into every cubic foot of timber; this gives a weight of from $1\frac{1}{2}$ lbs. to 2 lbs. of the sulphate for the smallest pole.

It is extremely difficult to inject larch unless it is of very open grain, and very free from resin. No other than quickly grown, soft timber is really suitable. The liquid cannot penetrate the heartwood, and it has sometimes happened in boucherised poles that the heartwood, which is more durable than the sapwood under ordinary circumstances, has rotted, leaving the sapwood sound.

Spruce and Scotch fir are very suitable, and the value of

the system is, that by it these cheaper descriptions of fir are rendered more durable than the more expensive sorts when unprepared.

The sulphate of copper must be free from iron. Sulphate of iron is inert, or possibly hurtful; besides this, the iron becomes oxidized by exposure to the air and forms a muddy deposit, which chokes the fine filter formed by the pores at the end of the pole, and thus stops the process.

As the sulphate always contains some iron, it is well to make a saturated solution and allow it to remain exposed to the air as long as possible, so that the iron may deposit at the bottom of the vessel, after which it can be diluted for use. The crystals may be placed in a wicker basket hung at the surface of the water, so that they may dissolve readily.

The solution should be diluted till it contains 1 lb. of the salt to 5 gallons of water. If it be too strong, it appears to contract the sap vessels and to crystallize at their ends.

The water must be free from lime and perfectly clear. If it contains lime, it is as well to add a little sulphuric acid to precipitate it, and either allow it time to settle or filter the water through sand, for even the slightest cloudiness interferes with the injection.

The air must be carefully expelled from the chamber formed at the butt of the pole. This is best done by inserting a wire between the pole and the packing which forms the side of the chamber. After the tap has been turned to admit the solution, the wire is withdrawn leaving a small hole, and when the water spirts out freely, showing that the air has escaped, this hole can be closed by a blow from a hammer; neglect of this precaution has frequently prevented the injection of the upper side of the entire pole.

As the sap which runs from the trees contains copper, it is allowed to flow into a reservoir, to be used instead of water to form fresh solution. The copper acts as an antiseptic on the putrescible substances in the sap, so that its employment is not injurious.

Although it is quite possible to inject trees which have been cut two or three weeks, the labour will be much more costly

than when the work is done quickly, because the pores contract in drying. It is always necessary to cut a thin slice from the end however recently the tree may have been felled, and if the injecting is not rapidly completed, the pores close, even although they are well wetted by the solution, and however carefully the water has been filtered they become choked by the substances held in suspension by the liquid, so that a slice has to be removed from time to time to expose a fresh surface. The apparatus should therefore be erected in the forest itself, so that the trees may be injected the day they are felled. They must not be twisted, crooked or scabby, or the pores will not be sufficiently open.

The process succeeds best in spring and autumn, because the sap is then most fluid and it is not so necessary to be prompt in the preparation; cold hinders it, and frost obviously stops it. It is little use to attempt it in winter. The pressure tank should be elevated about twenty-four feet; if it is too high, it is said that the liquid flows too rapidly through the timber to produce its best effect.

It has been found only partially successful for poles to be set in sandy or peaty soil.

Occasionally, even in suitable soil, one here and there has decayed rapidly without any apparent cause. This probably arises from the process having been imperfectly performed, for when this is the case the poles will not last as long as well-seasoned unprepared timber, because they have been cut in the summer and set while green.

Zinc and iron decompose sulphate of copper; the bolts and nails used for fixing insulators must therefore be well galvanized, or even tarred over to protect the zinc. This corrosion is especially troublesome in respect to the so-called earth wires or lightning conductors fixed to the poles, which will be corroded and need renewal in a few years; the second set will probably not be affected, because the timber will then be thoroughly dry.

In Belgium, the railway sleepers, which are generally of beech, were at one time boucherised, but it was found that when they were laid in damp soil, the decomposition of the

chairs and spikes replaced the copper by iron, so that the wood became rotten under the chairs while perfectly sound elsewhere.

A comparative trial of boucherised and of unprepared poles was made on the Wilts and Somerset Railway, in 1856. When examined in 1861 all the former were perfectly sound, while of the latter—

20 per cent. of those set in alluvial soil were decayed.

21	"	"	in clay	"
21	"	"	in gravel	"
40	"	"	in chalk	"

The Sub-Engineer of the Belgian Telegraph Service states that the probable duration of a boucherised pole in suitable soil is 20 years.

The French employ the process for all their poles. They have also injected dry timber with sulphate of copper by the vacuum process, but if the vacuum process is used at all it should be employed for creosote.

549. *Creosote*.—Creosote does not corrode iron; it does not seem to fail in any soil; and it has another advantage which may seem at first sight a singular one, it repels insects, so that they do not spin their webs in the insulators.

Creosoting can be carried on only at a large dépôt, and in practice is done by contract. Too low a pressure is sometimes used; water is mixed with the creosote, and the timber is allowed to get wet from exposure before it is placed in the cylinder. It is necessary in all cases to weigh trial poles both before and after the operation, to see that the proper quantity of 8 lbs. per cubic foot has been forced into the timber.

On the other hand, the apparatus for boucherising is inexpensive and portable; the process is readily overlooked, and it is easy to ascertain whether the solution has penetrated the entire pole by testing it with ferrocyanide of potassium, which produces a brown stain with copper.

550. The cost of the sulphate of copper process, calculated on 5,287 Scotch fir poles, injected in the forest, and averaging

25 feet in length, is about twopence per each lineal foot of timber:—

Timber	2·017	pence.
Sulphate of copper	·925	„
Labour, dressing the pole, and wear and tear of apparatus, with a payment of royalty	1·137	„
Total cost	<u>4·079</u>	„
Cost of preparation only	2·062	„
Cost of an apparatus to prepare 100 poles	£110	
Strength of solution	1 lb. to 5 gallons.	
Quantity of solution per lineal foot	1·4	„

The cost of creosoting, calculated on 20,409 poles averaging 25 feet in length of Baltic red pine, is under twopence per each lineal foot of timber:—

Timber	4·336	pence.
Carriage to and from the works	·359	„
Creosoting	1·486	„
Total cost	<u>6·181</u>	„
Cost of preparation only	1·845	„

551. Instructions for Out-door Jointing Gutta-Pereka Wire.

Preparatory.—The joint-box where the joints are to be made is first opened, the jointer's box placed close to one side of it, and then the tent placed over the box so that the opening in the tent is opposite the jointer's box.

Attached to the box should be two low stools for the jointer and his assistant to sit on, to keep them clear from the wet pavement or damp ground.

The box should be opened and the various tools, spirit-lamps, furnace, &c., placed where most handy; the spirit-lamp for the furnace should be lighted and the soldering iron heated:

the gutta-percha tools should, if dirty or sticky with compound, be filed and cleaned.

Great care must be taken to keep the gutta-percha sheeting perfectly clean and dry.

It is unquestionably the fact that some men are prevented from making good joints by causes affecting the perspiration of the hand, and, as a joint requires frequent touching, it is easy to understand that this affects the material and will prevent a proper junction between the coats.

It is also a fact that by reason of ill-health an experienced joiner is similarly affected and makes inferior joints.

The dirty work ought properly to be done by an assistant.

Cleansing Wires.—The wires at both sides must be thoroughly cleaned with white waste soaked in naphtha, until each wire becomes thoroughly clean, free from tar, dirt, and grease.

Cleansing Hands.—After cleaning the wires the joiner should very carefully clean his own hands, and dry them well. Naphtha will be found best for this purpose. Its disadvantage is that it has a tendency to harden the hand.

Trimming Ends.—No. 1 wire should then be taken up on both sides (it is best to begin with the lowest number and proceed in regular order) and the gutta-percha carefully trimmed off each end for about $1\frac{1}{2}$ inch, care being taken that the knife does not "nick" the copper; if this should happen, the copper must be cut off at the "nick" and the percha trimmed back.

Making Copper Joint.—The copper wire left bare should be scraped or emery-papered carefully, and then the two ends being brought together overlapping may be held by the pliers, and first one side twisted then the other; the entire twist should occupy about 3 turns each way, or $\frac{3}{4}$ inch, the surplus ends should then be cut carefully and close over, and being lightly touched with the pliers turned in, so as not to leave an edge sticking up.

Soldering.—The twisted joints should then be soldered, care being taken to knock off the superfluous solder. Great care must also be taken when soldering a joint, that no wires be immediately under it, but that the space underneath be quite clear. Hot solder dropping on gutta-percha heats it at once, and penetrates.

Clean Joint.—The ends and soldered joint should next be cleaned with naphtha.

Compound.—Then a stick of compound should be warmed, and a small quantity put on the copper and joint, and properly tooled over, so as to cover the joint equally. Before applying the tooling-iron it should be well wiped.

First Cover.—The ends of the gutta-percha are then slightly warmed and the actual ends nipped off with the fingers. One side of the percha should be well warmed for about 2 inches back, and then brought forward over the joint to the opposite end with a twisting motion; the end should be nipped off, the opposite end after heating should then be brought forward over the other part in a similar manner, as far as it will go; the percha should again be warmed and kneaded together with the finger and thumb, or tooled beforehand.

Compound 2.—After kneading, the joint should be warmed over slightly with the spirit-lamp, the compound should then be heated and applied over the gutta-percha, not by *dabbing*, but by putting the stick on the percha and *rolling* it along, sufficient will be found to adhere; the compound must be again warmed and applied a sufficient number of times to go thoroughly over the percha.

The joint should again be warmed, and the compound properly tooled until it covers the joint uniformly.

Second Cover.—A sheet of gutta-percha (the gutta-percha sheeting, as supplied to jointers, should be cut into strips 4 in. wide, and kept carefully in a bag or case), well cleaned, should then be warmed carefully over the spirit-lamp, and, when sufficiently warmed, a piece of about 1 in. should be cut off with a pair of scissors, whose edges are moistened with the lips (the pieces cut off may be put in the mouth to assist the formation of saliva), the ends should also be cut off; the joint is then warmed with the lamp, and also the piece of sheet that is held in the hand, previously having been stretched; the sheet is then applied to one end of the joint, $\frac{1}{2}$ in. on the old core from the end of the pull down, and being firmly pressed is drawn along the length of the joint; the superfluous end being cut off, the joint is then turned over, and the spirit-lamp applied so that the heat

warms both joint and sheeting; the sheeting is then pinched round the joint so that its sides meet above the joint, the upper part is also slightly pulled so as to make the adhesion better; the spare sheeting is then cut off with the scissors close to the joint, a warm tool is passed over the seam so as to open it again, it is again pinched up, and by so doing any air is forced out that may be in it. In pinching up the last time, one edge ought to overlap the other slightly, so that the warm tool more properly seals up the seam.

By cutting off the sheet too far from the joint the seam cannot be re-opened, and by cutting off too close no seam is left, and there is necessarily a vacant space in the second covering; this is a frequent fault, and should be avoided. By use of the tool the ends of the coating are made to amalgamate with the old material, the joint is again warmed thoroughly, and kneaded with the thumb and forefinger, care being taken to preserve its shape and to knead evenly all round, it is then rubbed up with the moistened hand.

Compound 3.—The stick of compound and the joint are again warmed, and the compound is rolled over the joint from end to end in about four places, which about covers the joint; the joint is again warmed, and the compound is worked and spread over the whole joint by means of the tooling iron in a uniform and even manner. The joint is again manipulated with the hand, and kneaded. It is then heated for the last time, and rubbed well with the hand, well moistened. This rubbing must be done uniformly and equally all round; it tends to solidify the joint, and gives it that highly-polished and finished appearance so characteristic of the handiwork of a good jointer.

The following notes respecting the joint and its manipulation should be carefully attended to.

Holding Core.—The jointer and his assistant should hold the wire carefully and firmly between the thumb and forefinger at such a distance from the joint as to be beyond the influence of the heat, the percha held should always be hard; if the hand be too near the joint the man will probably be pressing the material where it has been softened by the heat and will very probably cause damage.

Twisting Joints.—In turning the joint over for the purpose of heating or tooling, the jointer and his assistant should turn it over carefully together so as not to put a twist in the short portion, but to distribute it over the entire length. When that operation has been done the joint should be turned back in the opposite direction, so as to bring it into its original position. As in making a joint this twisting has to be done very often, it is very essential that this turning over and back again should be attended to, instead of turning the joint the same way always; from inattention to this and the preceding instruction, joints have been seen with a series of twists made outside the joint.

A jointer should bear in mind that a good jointer is known by the unaltered state of the core outside the joint, as well as by the excellence of the joint itself.

The application of the fingers to the joint is frequently necessary; the fingers, however, should be well moistened in the mouth before touching the warm material.

Whenever a joint has been touched by the moistened finger the joint should *always* be warmed with the spirit-lamp, as this drives away any moisture. *This is very important.*

If in warm weather the hand should perspire it ought to be dried. Naphtha will do this best, especially as its rapid evaporation produces coldness.

Sheeting of a *similar quality* to the gutta-percha of the wire itself should always be used. It is very difficult to produce a homogeneous joint by using two different materials.

The length of a joint should be about *six* inches.

The principal faults in joints are:—

Bad Twists.—Nicks in copper and leaving *one* end of twist sticking up; joints have been seen with one end nearly penetrating through.

Eccentricity.—Due to bad kneading and tooling.

Air-holes.—Due to bad closing of sheeting.

Burning.—Due to careless use of lamp and overheating.

Separation of Coatings.—Due to moisture remaining on coats and also to want of *cleanliness*.

Every detail of jointing may be learnt, and with practice become quite easy; but, *unless a jointer is scrupulously clean, his labour is nearly useless.*—(G. E. Prece.)

THE STRAINS OF SUSPENDED WIRES AND THEIR STRESS ON
STRUTS AND STAYS. (*Robert Sabine.*)

TABLE I.
TO FACILITATE THE CALCULATIONS OF STRAINS ON SUSPENDED (IRON OR
STEEL) WIRES.

Col. 1.	Col. 2.	Col. 3.	Col. 1.	Col. 2.	Col. 3.
Relation of sag to span. h : l	Proportional strain. K.	Proportional length (span = l). L.	Relation of sag to span. h : l	Proportional strain. K.	Proportional length (span = l). L.
1 to 10	4·67	1·02667	1 to 130	54·96	1·00016
1 „ 15	6·62	1·01185	1 „ 140	59·18	1·00014
1 „ 20	8·68	1·00667	1 „ 150	63·40	1·00012
1 „ 25	10·74	1·00427	1 „ 160	67·63	1·00010
1 „ 30	12·83	1·00296	1 „ 170	71·85	1·00009
1 „ 35	14·92	1·00218	1 „ 180	76·07	1·00008
1 „ 40	17·02	1·00167	1 „ 190	80·30	1·00007
1 „ 45	19·11	1·00132	1 „ 200	84·52	1·00006
1 „ 50	21·21	1·00107	1 „ 225	95·08	1·00005
1 „ 60	25·43	1·00074	1 „ 250	105·64	1·00004
1 „ 70	29·64	1·00054	1 „ 275	116·21	1·00004
1 „ 80	33·86	1·00042	1 „ 300	126·77	1·00003
1 „ 90	38·07	1·00033	1 „ 350	147·89	1·00002
1 „ 100	42·29	1·00027	1 „ 400	169·02	1·00002
1 „ 110	46·52	1·00022	1 „ 450	190·14	1·00001
1 „ 120	50·74	1·00019	1 „ 500	211·26	1·00001

RULES FOR USING THE ABOVE TABLE.

- I. *The span and sag being given, to find the absolute Strain per square inch section.*

RULE.—In column 1 find the nearest relation of sag to span, and opposite to it (in col. 2) the proportional strain (K). The absolute strain in lbs. is K times the span in feet.

EXAMPLE.—If a steel wire were to be stretched across a river (span 2,340 feet), and, on account of shipping, only 39 feet sag could be allowed, what would be the absolute strain?

$$39 : 2340 :: 1 : 60.$$

In the table opposite the proportion 1 : 60 is given (col. 2)

the proportional strain (κ) = 25.43 lbs. The absolute strain is, therefore,

$$25.43 \times 2340 = 59506 \text{ lbs. per square inch.}$$

II. *The span and sag being given, and also the sectional area of the wire in square inches, to find the actual strain in lbs.*

RULE.—In column 1 find the nearest relation of sag to span, and opposite to it (in col. 2) the proportional strain (κ). Then the actual strain in lbs. is,

$$\kappa \times \text{area of wire} \times \text{span in feet.}$$

EXAMPLE.—Span of 111 yards with a sag of 20 inches (= 1 : 200). Required the actual strain of a No. 11 B.W.G iron wire.

In col. 1 opposite 1 : 200 we find $\kappa = 84.52$. The sectional area of No. 11 wire is 0.0125". Therefore the actual strain will be

$$84.52 \times 0.0125 \times 333' = 352 \text{ lbs.}$$

III. *The span and sag being given, to find the length of the suspended wire.*

RULE.—In col. 1 find the nearest relation of sag to span ; col. 3 gives the proportional length (L). The actual length is = L times the span in feet.

EXAMPLE.—Span 200 feet, sag 10' = (1 : 20). The proportional length of which is

$$1.0067. \text{ Therefore length} = 1.0067 \times 200 = 201.34 \text{ feet.}$$

IV. *The span and maximum actual strain of a wire being given to find the necessary sag.*

RULE.—Divide the given maximum strain in lbs. by the area of the wire in inches multiplied by the span in feet, and with the quotient refer to col. 2 of the table for the nearest value. Opposite to this in col. 1 you will find the sag.

EXAMPLE.—It is wished to stretch a No. 8 steel wire across a space of 2,000 feet in such a way that the maximum strain

upon it will not exceed 900 lbs. The area of No. 8 wire is 0.023" and

$$\frac{900}{0.023 \times 2000} = 19.565.$$

In column 2 the nearest value to 19.565 is 19.113, corresponding to a sag of 1 : 45. The sag will therefore have to be

$$\frac{2000}{45} = 44\frac{1}{2} \text{ feet.}$$

V. *Two neighbouring spans of different lengths, which do not form an angle at the post, being given, to find the sag which one wire must be allowed in order to balance the strain of the other on the common support.*

RULE.—Having found the actual strain of the first section, the sag of the second is calculated by the Rule IV. given above.

EXAMPLE.—A span of 2,000 feet is crossed by a No. 8 wire (area = 0.023") having 44½ feet sag (1 : 45), and therefore an actual strain of

$$19.11 \times 0.023 \times 2000 = 879 \text{ lbs.,}$$

the neighbouring span is only 400 feet.

$$\frac{879}{0.023 \times 400} = 95.5 \text{ (see Rule IV.).}$$

In col. 2 the nearest value to this is 95.08, corresponding to a sag of 1 : 225. The wire must, therefore, be pulled up till the sag is

$$\frac{400}{225} = 1.8 \text{ feet, or about } 21\frac{1}{2} \text{ inches.}$$

VI. *Two neighbouring spans having different strains, and making an angle at the post, to find the proper direction for a strut or stay.*

RULE.—Find by the foregoing rules the two strains. Measure off from the pole in the direction of each wire a length propor-

tional to its strain. Join the ends of the measured lengths by a straight line, the middle point of which, sighted towards the post, gives the proper line of strut and stay.

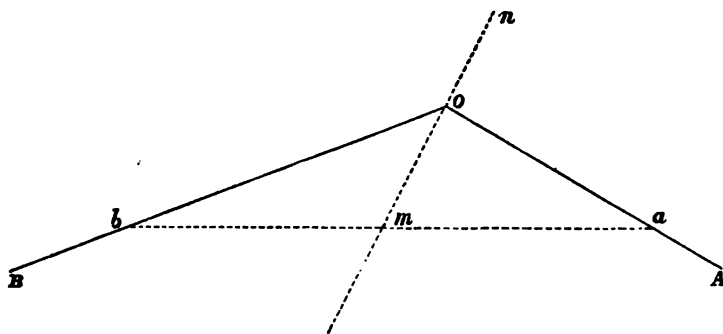


FIG. 134.

EXAMPLE.—From the post o are two wires; the strain of A is 600 lbs., that of B is 900 lbs.

I measure off, in the direction oA , a length of 10 feet to a , and in the direction oB a length of 15 feet to b (because 10 and 15 are proportional to 600 and 900). The points a and b I then join by a straight line ab , the middle of which is at m ; therefore a strut should be placed in the line mo . If I want a stay I sight the line on the other side of the post, towards n , and place the stay in the direction no .

VII. *The span, sag, and temperature (in deg. Centigrade) of a wire being given, to calculate the effects of an alteration of temperature.*

RULE.—1. Take from col. 3 of the table the proportional length, corresponding with the given span and sag.

2. Then $\left\{ \begin{array}{l} \text{increase} \\ \text{decrease} \end{array} \right\}$ this proportional length by 0.0012 per cent. for every degree Centigrade which the altered temperature is $\left\{ \begin{array}{l} \text{above} \\ \text{below} \end{array} \right\}$ the original temperature.

3. Lastly, with the altered proportional length, find (in
B B 2

col. 3) the nearest value, and in col. 1 the corresponding sag. The proportional strain in col. 2, multiplied by the span in feet, gives the resulting strain in lbs. per square inch of section.

EXAMPLE.—An iron wire was stretched across a span of 400 feet, with a sag of 5 feet (1 : 80), at a temperature of 25° C.; the absolute strain upon it was, therefore,

$$400 \times 33.86 = 13544 \text{ lbs. per square inch.}$$

In winter, during a frost of 5° C., what would the sag and strain become?

1. By col. 3 we find that the proportional length for sag 1 : 80 would be 1.00042.

2. The difference of temperature (+ 25° to - 5° C.) would be 30°, and 30×0.0012 per cent. = 0.036 per cent. Then $1.00042 - 0.036$ per cent. = $1.00042 - 0.00036 = 1.00006$.

3. In col. 3 we find the proportional length 1.00006 corresponding to a sag of 1 : 200, and (col. 2) a strain of about 85 lbs. $85 \times 400 = 34,000$ lbs. per square inch, which would be sufficient to permanently stretch the wire.

VIII. To find the actual $\left\{ \begin{smallmatrix} \text{stress} \\ \text{strain} \end{smallmatrix} \right\}$ on a given $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$ placed in the proper direction.

RULE.—1. Mark out by the method given in Rule VI. the line of direction, and measure the distance mo in feet. The horizontal strain on the post, in the direction nm , is equal to the actual strain on A in lbs., multiplied by twice mo in feet, and divided by oa in feet.

2. Next measure downwards and mark from the point where the $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$ joins the post, a length of 10 feet on each, and with a tape measure the distance across in feet between the two marks.

3. Find in the following table (col. 1) the nearest value to this distance, and with the corresponding number given in

col. 2, multiply the horizontal strain found (in 1) above. The product is the actual strain on the $\left\{ \begin{array}{c} \text{strut} \\ \text{or} \\ \text{stay} \end{array} \right\}$ in lbs.

TABLE II.

TO FACILITATE THE CALCULATIONS OF STRAIN ON STRUTS AND STAYS.

Col. 1.	Col. 2.	Col. 1.	Col. 2.
Distance between strut or stay and post 10 feet down.	Proportional strain on strut or stay.	Distance between strut or stay and post 10 feet down.	Proportional strain on strut or stay.
Ft. in.		Ft. in.	
2 0	5.02	5 0	2.07
2 3	4.47	5 6	1.89
2 6	4.03	6 0	1.75
2 9	3.67	6 6	1.63
3 0	3.37	7 0	1.53
3 3	3.12	7 6	1.44
3 6	2.90	8 0	1.36
3 9	2.71	8 6	1.30
4 0	2.55	9 0	1.24
4 3	2.41	9 6	1.20
4 6	2.28	10 0	1.16
4 9	2.17		

EXAMPLE.—The post in the example given with Rule VI. is provided with a stay in the line mo . The length of the

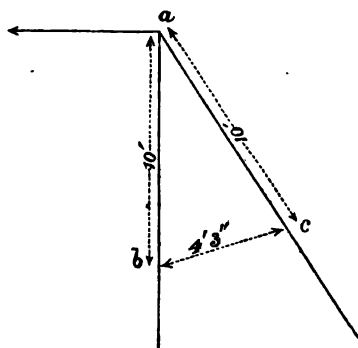


FIG. 185.

line $m o$, by measurement, I find to be 6'; the horizontal strain on the post is, therefore,

$$10' : 600 \text{ lbs.} :: 2 \times 6' : 720 \text{ lbs.}$$

I next mark off from the point a 10 feet to b on the post, and c on the stay, and measure the distance b to c , which I find to be, say, 4'. 3".

Lastly, I refer to the table, and opposite 4'. 3" I find 2.41.

The strain on the stay is, therefore,

$$2.41 \times 720 = 1735 \text{ lbs.}$$

In this rule it is supposed that the strut or stay touches the post, at the same height as the mean strain acts horizontally.

If, however, the strain at a is higher or lower than the top of the strut or stay, the result found in the foregoing must be multiplied by the height of the strain, and divided by the height of the top of the strut or stay, both being measured on the pole.

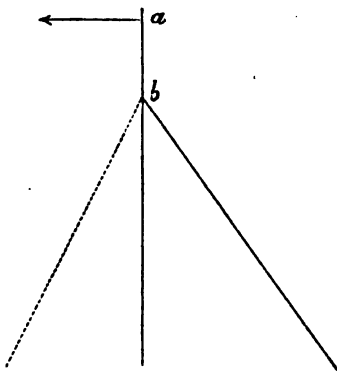


FIG. 136.

EXAMPLE.—Suppose in the last example the mean strain acts at 20 feet from the ground, but that the stay reaches only 15 feet up, then the actual strain will be

$$\frac{1735 \times 20}{15} = 2313 \text{ lbs.}$$

IX. *The horizontal strain in the proper direction of a $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$ and the maximum strain on the $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$ being given, to find the angle at which it must be placed against the post.*

RULE.—1. Find by Rule VIII. (1) the horizontal strain in the proper direction of the $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$.

2. Divide the given maximum strain by the horizontal strain, and find in col. 2, Table II., the nearest value to the quotient; col. 1 then gives the distance which the $\left\{ \begin{smallmatrix} \text{strut} \\ \text{stay} \end{smallmatrix} \right\}$ must stand from the post, at a point measured 10 feet down from each.

EXAMPLE.—Suppose the horizontal strain calculated by Rule VIII. (1) to be, as in the last example, = 720 lbs., and that a stay which must not bear more than 1,500 lbs. is to be used,

$$\frac{1500}{720} = 2.08,$$

in col. 2, Table II., the nearest value to this is 2.07, and in col. 1 the corresponding distance between the 10 feet marks is given = 5 feet.

AUTOMATIC SYSTEMS.

Although a good manipulator may be able to send 40 or more words a minute by the Morse key, practically a very much lower rate is attained; the exertion cannot be sustained: and however expert a clerk may be, his signals are not always clear and legible. If, therefore, a machine can be employed which shall do nothing more than transmit signals at the maximum speed which can be attained by hand, the usual advantage of machine over hand labour will have been gained. The machine

will not tire, and its signals will always be perfectly formed and clear.

But obviously a far higher speed can be attained by mechanical than by hand signalling: it would be almost unlimited were it not for the effects of induction, which is always present even in a suspended wire. At moderate speeds the retardation and prolongation is not felt, because its duration is but a small fraction of the time between one signal and another; but as speed increases the interval between each signal becomes less and less; so that at a certain speed the effect, however short in duration absolutely, lasts during the whole of the interval. It is clear that we can adjust the necessary *compensations* for counteracting the effect of induction more accurately by mechanical means than by hand.

Automatic telegraphs produce the Morse alphabet, or even give a fac-simile of handwriting; the latter system is not at present sufficiently employed to need notice in a practical treatise such as the present.

The earliest attempt to transmit Morse signals automatically was the decomposition process of Bain (389), under which the ordinary Morse characters are punched out in a paper ribbon and transmitted by means of a brush of wire resting upon the ribbon, and making contact with a metallic roller through the holes cut in the paper; they are received upon chemically prepared paper, or by the ordinary inkwriter.

This system was employed in 1852 between Liverpool and Manchester, but was abandoned partly because the insulation of the wires was not sufficiently good, but principally because no convenient method of perforating the paper had then been contrived. It, however, now succeeds very well at a speed of 60 or 70 words, on about 100 miles of suspended wire, when an inkwriter is used for receiving, and is more successful still with chemically prepared paper.

The punching apparatus can be made in a simpler form if the perforations are arranged in parallel lines, one for dashes, the other for dots, instead of one single line. The same wire brush will make contact through both rows of holes, and the received signals will be unaffected by the alteration.

The limit of speed with an inkwriter is quickly reached when the length of the dots and dashes of the Morse alphabet is determined by the *duration* of the battery currents. A higher speed can be attained by Bain's chemical process, but the current commences to mark the prepared paper long before it attains sufficient strength to produce a legible signal, so that the elements of the letters instead of commencing and ending sharply, taper off to a fine line which even at moderate speeds reaches from one to the other. This line (technically called the "*drag*") is caused by the residual charge of the wire, and as speed increases the line thickens until the signs become illegible. If a reversed current exactly of the right strength to neutralize the prolongation which causes this *drag*, and which varies with the order of sequence of dots and dashes, could be applied, speed would be enormously increased and a more sensitive paper, capable of being acted on by a weaker current, could be used.

This has been partially effected by reversed batteries, but, it would seem, is successfully accomplished by Mr. Edison of New York, by means of the extra current from electro-magnets, used in the manner of a shunt. Under the first system the current is reversed at the sending end between each signal, and a small *shunted* battery connected so as to oppose the marking current is placed at the receiving end; the number of cells and resistance of shunt of this battery are adjusted so that the sending current works through it, but when the signal current decreases, its own current, being in the reverse direction, is sufficient to neutralize the charge remaining in the wire in the interval between signals.

Edison uses punched paper perforated on Bain's system; and a very powerful battery, at the sending end only, shunted by electro-magnets, so that their extra current direct, which is powerful, acts as a reversal to discharge the wire at the sending end. The paper at the receiving end is prepared with iodide of potassium and starch, so as to be exceedingly sensitive, and is shunted in like manner by electro-magnets, whose extra current passes through the paper in the interval between signals in a reverse direction and prevents the *drag*.

The shunt is made up of several separate electro-magnets, or

resistances wound on iron bobbins, and is arranged so that by means of a sliding contact the exact number of magnets to produce the required amount of extra current can be put in circuit. A speed of 400 to 500 words per minute has been attained experimentally, on a suspended wire 200 miles long, by this means with careful management and under favourable circumstances.

A succession of dots can be signalled much more rapidly than dots and dashes, because the battery contacts are of uniform duration, and the charge in the wire uniform also, whereas a dash charges the wire more highly, and therefore requires a larger reversal, or a longer time for its discharge. In addition to this effect of inequality in the duration of the currents, there appears to be also, when an inkwriter is used, an important action upon the receiving electro-magnet; for if a current is prolonged the iron is more strongly magnetized, and therefore requires more time to become neutral. It is therefore desirable to produce dashes and dots by currents of equal duration; this can be effected by adjusting the armature of a polarized relay so as to be neutral, or in other words, to have no tendency to move at all except as influenced by the current.

Siemens as well as Wheatstone has adopted this principle. The armature of the receiver being polarized, and so adjusted as to remain in the position in which it is left by the last current, it follows that after a marking current has been sent the inking disc continues to produce a line on the paper until it is removed by the reversal. Thus a dot is produced by an instantaneous current, immediately succeeded by a reversal; a dash by an equally short current, reversed after an interval sufficient to allow a dash to be formed on the paper.

Siemens, like Bain, uses the wire brush to make contact through the perforations in the paper ribbon. The edge of the wheel, on which the paper rests, instead of being in one piece, as in Bain's apparatus, is divided into a number of insulated teeth, connected alternately to the positive and negative poles of a battery, so that if the brush rests upon the moving wheel when the paper ribbon has been removed, a series of reversals is sent along the line. When the ribbon is in place no current is sent until the brush meets with a

perforation; if this happens to lie over one of the positive teeth of the wheel, a positive signal is sent, and *vice versa*. If a dot is required, two holes are punched at a distance one from the other equal to that between *two* of the teeth, so that the wire brush first makes contact with a positive tooth or division of the wheel, and immediately after with the next tooth, which is negative; a marking current is therefore sent and reversed instantly. If a dash is required, the holes are punched at a distance equal to that of *four* teeth; the reversed current is now produced, not, as before, by the *next* tooth to that which sends the marking current, but by the *next but two*; that is to say, the first tooth being positive, causes the armature to be attracted; the second, which is negative, does not act, nor does the third, which is positive, there being no holes in the paper over them; but there is a hole over the fourth tooth, which, being negative, reverses the current.

A second and parallel line of holes is punched in the sending ribbon, forming a kind of rack to receive the teeth of a wheel which carries the paper forward; this secures accurate coincidence between the perforations and the divisions of the wheel over which the paper runs.

It would, however, appear that the system of making contact through slits or perforations is not perfect; the contacts are apt to be interfered with by dust and the fibres of the paper itself, and the duration of the contacts is shortened by the brush or spring being compelled to drop through the band and to be lifted again by the edges of the perforations. So much is this the case, that a much better result is obtained by lengthening the perforations, and increasing the speed of the band in a corresponding degree.

Wheatstone has avoided this defect completely. In his system the contacts are made, as in a key or relay, by levers tipped with platinum, and the paper band simply regulates the movement of these contact pieces, in the same manner as the cards of a Jacquard loom determine the lifting of the threads of the warp.

The apparatus, as originally arranged, produced, like Siemens', dots by a positive current followed immediately by a negative

of the same duration and strength, and dashes, by a similar pair of currents separated by an interval during which the wire was insulated at the sending end.

But it was soon found that although greater speed was attained by the system of instantaneous currents than could be obtained by "permanent" or constant currents, a new series of imperfections were introduced owing to the leakage of the line during the intervals between the currents.

This is very well seen in a circuit where there is considerable induction, as when cables are connected to land lines.

When a cable, say, 120 miles long, is placed between two land lines A and B, of 20 and 130 miles respectively, the rate of transmission from A to B is considerably higher than in a reverse direction, in fact about as 9 to 6; and although the ordinary effect of an increase in the resistance of a land wire is to decrease speed, it will be found that when short currents followed by insulation of the sending end of the wire are used, the speed from A to B is increased by employing a wire for line B of 170 mils. gauge in place of one of 240 mils. But in speaking from B to A, the thicker wire will give the best results.

That is to say, the line between the battery and the cable should be decreased in resistance (the battery itself having as low a resistance as possible), while, on the other hand, the resistance of the line between the cable and the receiving instrument should be increased. In the case under consideration as much as five thousand ohms may be inserted at the receiving end with advantage: that is to say, a resistance considerably greater than that of the rest of the circuit; the object being to secure a high and uniform potential in the cable, and for this purpose to prevent its discharging itself too quickly at the distant end. This gives a heavier mark and a greater range of adjustment of the receiving instrument.

But when the land line B is increased to 300 miles, and the cable is reduced to 60 miles, A remaining unaltered, the addition of resistance to A, when A receives, does not produce the same effect; for the potential of the end of the cable adjoining line B cannot be raised so high as in the case where the land line is shorter. Here the speed from B to A is only about one-

half that in the reverse direction, or about 40 and 80 words per minute respectively.

It is frequently advantageous, even when there are no cables in circuit, to introduce a considerable resistance at the receiving end, and to adjust it from time to time to suit the varying condition of the circuit as regards capacity and insulation; and as a very feeble "contact" or leakage from wire to wire affects the delicate apparatus, it is frequently advantageous to introduce resistance at the receiving end to decrease the tendency to the admission of false currents.

In addition to the prevention of loss to earth by the addition of resistance at the receiving end, it is necessary to compensate for the irregularity of *interval* between the positive and negative currents (irregularity of *duration* is avoided by the system of equal current or dots), so that the potential of the wire may be kept as nearly uniform as possible at the commencement of each signal. This is effected by an arrangement of the apparatus by which weak currents are sent in the intervals during which under the original system the wire was disconnected. The first and last current of a dot or dash pass to line direct, and in the spaces compensating currents pass to line through a high resistance, which can be varied at will so as to increase or diminish the strength of the currents.

A further increase of speed is obtained by placing a condenser between the line and the receiving instrument, the plates being connected or shunted by a high resistance. A condenser at the sending end lowers speed by causing the marks to run together.

Wheatstone's system now embraces three methods: (a) called the *permanent* current system, (b) the *intermittent* current, and (c) the *compensation* system.

In (a) the signs are formed precisely as with the double current key, the *marking* current lasting during the whole signal, and the *spacing* (or reversed) current during the whole interval between signals; but in (b) a dot is formed by a short marking current, instantly followed by an equally short reversal, a dash by a short current, followed first by disconnection of the line-wire, and afterwards by a short reversal, as has been already explained.

In system (*b*) the disturbing effects are exactly opposite to those in (*a*), the compensation is, in fact, overdone. In the third, or most improved system (*c*), the over compensation of (*b*) is avoided.

The letter R (- — -) shows the effects of the three systems very clearly.

When "permanent" currents are used (*a*), the spacing charge remaining in the wire in the interval between the letters partially neutralizes the marking current for the first dot of the R, which consequently is shortened. The long marking current for the dash charges the wire so highly, that the succeeding spacing current does not neutralize it quickly enough to cut off the dash at the proper time, so that the dash is elongated. Again, the dot after the dash is also elongated, because the next marking current commences to act too soon, in consequence of there being too weak a spacing charge in the wire.

When intermittent currents (*b*) are used, the opposite effect takes place, the dot before the dash is elongated, and the dot following a dash is shortened.

Taking the letter R again as an example. No current having been sent during the latter part of the preceding space, the line-wire is clear and receives a full charge from the marking current for the dot; the following spacing current is immediately succeeded by a marking current for the dash, and during the remainder of the dash no current is sent to line. Two marking currents are thus sent to one spacing current, and the tendency is for the dot and dash to run together, owing to the line being charged to excess by the marking current.

In the case of the dot following the dash, the reverse occurs. At the end of the dash, owing to the long interval since the marking current was sent, the line may be considered as almost free of charge, and therefore receives the full charge from the spacing current which terminates the dash; this spacing current is followed by the marking current for the dot, which is again immediately followed by a spacing current. Thus two spacing currents are sent against one marking, and the dot is shortened by the excess of spacing currents.

In order to compensate for the variations in the residual

charge of the wire, caused by the unequal intervals between the currents, a middle course (*c*) is adopted: instead of causing the currents to cease altogether, they are weakened after the initial impulse—in a dash the strong marking current is followed by a weak current of the same sign; and in a similar manner the initial spacing current is followed by a weakened spacing current. The potential of the wire is by this means kept more uniform.

Taking the letter *K* as before, the tendency of the dot to run into the dash is prevented by the wire being already charged from the weak spacing current preceding it; a dot following a dash is prevented from being shortened by the weak marking current during the dash.

No compensating current is required in a dot, because, in forming it, there is no interval of disconnection.

The diagrams facing page 400 show the electrical portion of Wheatstone's automatic apparatus, with the last improvements (1873). It consists of three portions: the Perforator for preparing the paper ribbon, the Transmitter, and the Receiver.

The Receiver.—The writing is in the ordinary Morse code, the writing disc is actuated by the armatures *T T'*, Fig. 6, which are magnetized by induction from the permanent magnet. *S N*, Fig. 7, is an end view of the electro-magnets.

The armatures are adjusted so as to have no tendency to move except when acted on by the current, therefore the inking disc when brought into contact with the paper continues to mark till it is removed by a reversed current.

The writing disc is caused to revolve by the maintaining power of the instrument, and takes its ink from the groove of a larger disc, which is also kept in motion by the maintaining power; this disc dips into a reservoir of ink, and its groove being supplied by capillary attraction, the smaller disc takes its supply from the larger one, without any friction against it.

The paper ribbon (Plate 2, Fig. 8) is prepared by an instrument containing three levers, one of which produces two holes at right angles to the paper for a dot, another two holes diagonally for a dash, and a third smaller holes in the centre of the ribbon, forming a *rack* by which the paper is carried forward in the

transmission of a message. The dot and the dash punch act also upon the third or centre punch. They are either struck with a small mallet or by pistons actuated by compressed air. In the latter case the punching is performed by means of three keys, whose touch is as light as those of a pianoforte. The paper is dipped into hot olive oil.

The Transmitter is driven by a weight, and its speed can be adjusted between 20 and 120 words a minute. The perforated paper is carried forward by the teeth of a star-wheel, not shown in the drawing, driven by the wheelwork engaging the centre row of holes in the ribbon, and is kept in close contact with the star-wheel by a grooved friction roller.

An ebonite rocking beam *B*, Fig. 1, is kept in constant motion by a crank connected to the wheelworks; in it are fixed two metallic studs, that on the left-hand is connected to down-line, that on the right to one side of the divided disc *D*.

Under the beam lie the levers *A* and *B*, pivoted independently, but in electrical connection through the frame of the instrument. These levers are not *fixed* to any of the moving parts of the apparatus, but are simply pressed upwards by spiral springs, so as to follow the movements of the rocking beam, and so long as they remain in contact with the studs inserted into this beam there is unbroken connection between the down-line and the disc *D*.

D is the battery commutator or pole-reversor, it is divided into two parts, insulated one from the other; on each half is a stud which makes contact with one or other of the battery levers *C* *Z*, as the disc is moved from side to side; the right-hand half of the disc is connected to the left-hand pin of the rocking beam, and the left-hand side of the disc to the up-line. When the apparatus is in the position shown by Fig. 1, zinc is connected to up-line, and copper through the rocking beam and its levers to down-line.

The disc *D* is moved so as to reverse the battery current by the movements of the rocking beam *B*, communicated through the levers *A* *B* and the rods *H* *H'*, by means of the collets *K* *K'*, which pass loosely through the pieces *P* *P'*, fixed to the top and bottom of the disc.

As the rocking beam *R* oscillates, the reversing disc is pushed from side by these collets, and the roller *E*, which is fixed on a spring, jerks it over after it has been pushed over the centre by either of the collets, and thus prevents the necessity of the shoulder of the collets remaining close to the pieces through which they pass, which would interfere with the contact between the pins on the rocking beam and the levers *A B*. The roller also retains the disc in position, when pushed over by one collet, until it is pushed over to the other side by the other collet. A pin shown white in the diagram (screwed into the lever *C*), rests on a piece of ebonite in the lower bar *Z*, when in the neutral position (Fig. 2), so as to prevent the battery being put on short circuit during the reversal.

So long as the levers *A* and *B* are able to follow the movements of the rocking beam, the circuit remains unbroken, the reversing disc is pushed over alternately from side to side, and reversals are sent to line. This happens so long as there is no paper ribbon to interfere with the upward movements of the *needles* *S* and *M* attached to the levers *A* and *B*. But when a perforated paper ribbon is placed in the apparatus, the needles *S* and *M* determine whether line-contact shall or shall not be broken by the oscillation of *R*; they rise alternately until they touch the paper ribbon (Fig. 8); if there be a hole opposite their points they pass through it, and the contact is undisturbed; but should there not be a hole their motion and that of the lever is stopped, and as the stud on the rocking beam continues to rise, contact is broken between it and the lever. *M* plays into the upper row of holes in the ribbon and regulates the *marking* currents, *S* into the lower row regulating the *spacing* currents.

When a needle passes through the paper the commutator disc *D* is pushed over as shown by Figs. 1 and 2; but when the needle is stopped by the paper, the lever does not move sufficiently to enable the collet to act on the disc, and it remains in its previous position. This is shown by Figs. 4 and 5.

The apparatus is arranged to produce signals in three ways:—

- (a) By persistent currents, as by a double current key.
- (b) By intermittent currents, where a signal is commenced by a short *marking* current, lasting but an instant, and finished

by an equally short *spacing* current of the opposite sign, no current whatever being sent in the interval, the line being then entirely disconnected.

(c) Signals are commenced and ended by short currents in the same manner as in (b); but instead of the line being disconnected in the interval a large resistance is inserted, so that the last current sent continues to flow, but is weakened by the increased resistance of the circuit.

A resistance coil *R* is placed between the studs, as shown in the plate, so that when connection is broken between either *A* or *B*, and its corresponding stud on the rocking beam, the resistance is thrown into circuit.

In *a*, all the pegs of the resistance coils *R* are inserted, so that the resistance of the circuit remains uniform, whether the needles pass through the ribbon or not. But the needles still continue to regulate the movements of the commutator *D*, and the apparatus acts as an ordinary double current key.

In (b) the infinite peg of the resistance coils *R* is taken out, and therefore the line is completely disconnected when either needle fails to pass through the ribbon.

In (c) the resistance of *R* is adjusted until a current, of the exact strength required for compensation, has been obtained.

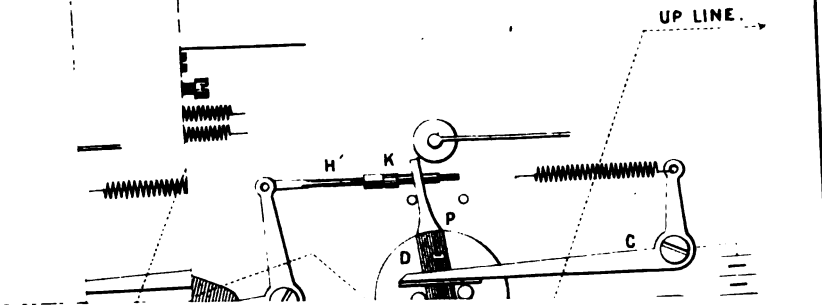
Fig. 1 represents the transmitter when sending a marking current. The lever *C*, which is in connection with the copper pole of the battery, rests on the left-hand pin of the reversing disc, which pin is in connection, through the pins on the beam and the levers, with the down-line; the copper pole is thus in connection with the down-line.

The zinc pole of the battery is in connection with the up-line, through the lever *Z*, and right-hand pin of the disc. Fig. 3 shows the reverse of this position, when the copper pole of the battery is in connection with the up-line, and the zinc with the down, so that a spacing current is sent.

The performance of the apparatus can be best shown by tracing the positions of the transmitter when actual signals are being sent.

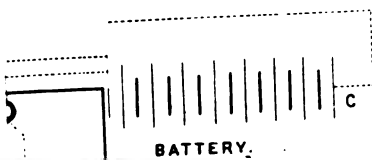
Take for instance the letter *A* (Fig. 9). The first movement for the dot is shown in Fig. 1. The second movement is shown by Fig. 3. The third movement is the commencement of the dash,

FIG. 3.



ERRATUM.

Page 386, Plate 1. The wire leading from the left hand side of the disc v in fig. 2, should be connected to the upper of the two terminals of the transmitter switch leading to the resistance coils R , instead of to the lower one.



TRANSMITTER SWITCH IN POSITION FOR
ENDING AUTOMATICALLY.



FIG. 6.

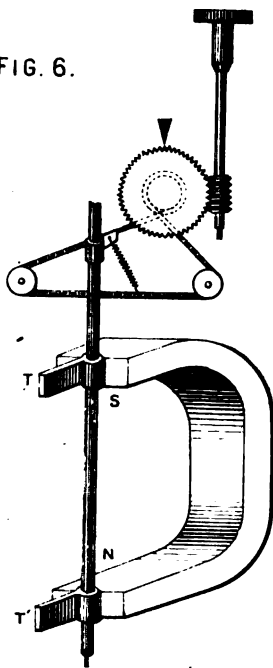
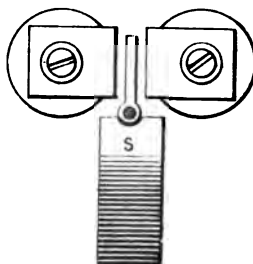


FIG. 7.





and is similar to the first movement for the dots. The fourth movement is similar to Fig. 3; but there being no hole in the paper the lever cannot rise, and contact is broken at the left-hand pin on the beam. The disc is not pushed over, and the marking current continues; but as it is now sent through the resistance coils, it may be weakened to any desired extent by modifying the resistance. The fifth motion is similar to Fig. 1, with the exception that as the needle *N'* cannot rise, the reversing disc still remains in the marking position, and the weakened marking current continues to pass through the resistance coils.

The sixth motion is represented in Fig. 3, where there is a hole in the paper opposite the lever *N*, the reversing disc is pushed into the spacing position by the collet on the rod *H*, and a spacing current is sent.

In a space the currents are sent in a similar way, but in a reverse order, and during a space of any length, a continuous spacing current is sent of the desired strength.

Fig. 9 shows the series of movements and succession of currents forming the letters *A I T*, and the numerals indicate the order of the movements of the needles *s* and *M*, which pass through the paper ribbon, where there is a perforation, and are stopped by it where no perforation is shown.

A higher speed is obtained by substituting a Bain receiver with a sensitive chemical paper, for the inkwriter.

THE DUPLEX SYSTEM.

By the *Duplex* system the working capacity of a wire is doubled, as it is possible to signal from both ends of the circuit at the same time, independently. The system is not altogether new, but it had never been usefully applied before its revival in an improved form by Mr. Stearns, to whom the author is indebted for a detailed description of his methods. Its earlier failure was partly owing to the same causes as those which affected the earlier trials of the automatic system.

There is, confessedly, a great difficulty in realizing the principle, and it may be well to make use of more than one method of illustration.

Telegraphists are but too well aware that when two stations dispute for the possession of a circuit, the signals of each are affected by those of the other. If the instrument is a single needle, it is found that when the direction of the two currents is the same, the needle moves more strongly than usual, and when the direction differs the needle scarcely moves at all. The fact that the effect of the current received from another station is visible even while one is signalling, is therefore familiar, and it may not be difficult to conceive that, if it were possible to separate the effect of the *outgoing* current on the needle, from that of the *received* current, the signals of the distant station might be legible.

Again, let us consider what occurs in testing a line wire between two stations, for resistance with the differential galvanometer. Until the resistance of the rheostat (or resistance coils) has been made equal to that of the line, the currents sent by tapping the key attached to the galvanometer move the needle, in the one direction if the resistance of the rheostat is too small, in the other direction if the resistance is too great. But immediately a balance is obtained, or in other words, when the two resistances have been made equal, currents or letters sent by the key at A do not move the needle at all, because the current divides equally between the coil connected to the rheostat and that connected to the line, which two coils being wound in opposite directions counteract one another: but each current or letter reaches B and can be read off on B's ordinary instrument, which we will suppose has been left in circuit.

If B now holds down his key, his current will either aid or oppose, strengthen or weaken, the current sent by A on the *line*, but can have no effect on that passing through the *rheostat*. A's galvanometer will therefore move because the balance has been disturbed. When the two sets of currents coincide in direction, more will flow to the line than through the rheostat, when they differ the contrary effect will happen.

If instead of sending a steady current B sends Morse letters,

the balance at A will be disturbed by each current, and the signals of B will be legible by A. For if while A is testing, B *interrupts*, as it is called, it is clear that each interruption will be indicated by the movement of A's needle. But B will not be able to read the signals sent by A, because the currents he himself is sending will pass through his own instrument, and therefore interfere with and confuse A's signal; still there is no reason to suppose that the arrangement which prevents this confusion as regards A, may not be equally successful at B.

If B now places a differential galvanometer in circuit, and obtains a balance by means of a rheostat, as if he were testing the wire to A; his own currents will not affect his needle, but the currents sent by A will move it, just in the same manner as B's currents moved A's needle.

So long then as the resistance of the rheostats at each end are made equal to the resistance of the circuit tested, each station will see the effect of the current sent by the other, although neither can see the effect of his own current.

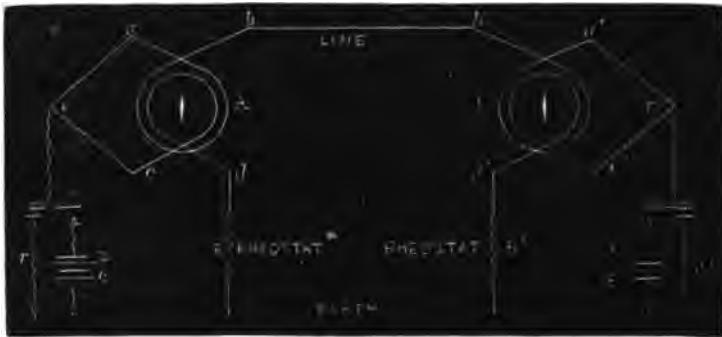


FIG. 137.

Let A and B (Fig. 137) represent the differential galvanometers, rheostats, keys and batteries at the two stations. Let the copper of the battery at A, and the zinc of that at B be connected to earth; so that when both keys are pressed simultaneously, the currents flow in similar directions and assist one another.

(1.) When either station (say A) signals alone, the current sent divides equally between the line and the rheostat because the resistances $e a b b' a' e' r'$ and $e c d R$ are equal. But as it

passes through the two coils of the galvanometer at A in opposite directions and as the current in each coil is of equal force, its effects are balanced and the needle is not moved.

At B, however, as it passes through only one of the two coils, following the path $b' a' e' r'$; a signal is produced.

(2.) If both A and B depress their keys at the same moment, the forces of the two batteries are added one to the other as far as the *line* circuit is concerned; but the rheostat circuit is in each case traversed by the current from the battery of its own station alone. The current is therefore stronger in each case in the coils connected with the line than in those connected with the rheostat, and consequently the needles of both instruments are moved. The effect on each instrument is similar to that which would be produced by decreasing the resistance of the line, leaving the resistance of the rheostats unaltered.

The batteries are generally so connected as to assist one another, but they may be opposed.

In practice it is not necessary to maintain an accurate balance. Were it not so, the system would scarcely be applicable to aerial lines on which the resistance is subject to frequent large changes due to loss of insulation from damp.

The earth connection to the back stop of the key, is not used on circuits under 100 miles, and it is found the rheostat resistance may often be halved or doubled without affecting the signals.

The duplex principle is applied to the needle instrument by winding the coils differentially. Electro-magnets are wound also differentially, so that the magnetism induced by the one coil counteracts the effect of the other so long as equal currents pass through the two, and when the equality of the currents is disturbed the core is magnetized by the more powerful of the two to an amount equal to their difference.

The two branches of an electro-magnet wound in the ordinary manner (Fig. 40, page 72) may be made to counteract one another by connecting the key to the wire connecting the two half coils, so as to produce an electro-magnet whose poles are alike instead of opposite; placing one half in the line and the other in the rheostat circuit.

This arrangement can also be applied to a polarised relay,

and answers very well for short lines, but is subject to grave inconveniences when used on longer circuits, because, even supposing the two branches of the electro-magnet to be wound so as to be perfectly equal in force, they are really differential in effect only when the armature is exactly equidistant from their poles, because its inductive effect, though slight, is sufficient to disturb the balance when the magnetized armature approaches the one and recedes from the other during signalling. This defect increases as the play of the armature is increased.

It is better, therefore, to wind the relay with two equal and parallel wires, differentially.

The duplex arrangement is also applicable to the double-current system, for each outgoing current is balanced, as will readily be seen by a consideration of the effect upon a differential galvanometer.

The duplex effect can be also obtained by arranging the apparatus and line in the form of a Wheatstone bridge, placing the Morse or relay in the position ordinarily occupied by the galvanometer of the bridge.

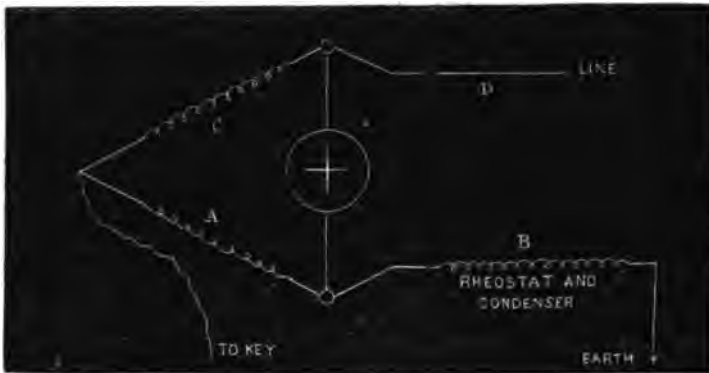


FIG. 138.

The rationale of this arrangement is precisely similar to that of the differential. Neither instrument is affected by outgoing currents, so long as the resistances of the line and of the

rheostat are equal, but if anything occurs to alter the resistance of the line, the instrument is affected precisely as if it were the galvanometer used in testing for resistance, and as a current from the distant station either assists or counteracts the outgoing current, it affects the balance of the bridge precisely in the same manner as an alteration of resistance.

When the stations work singly, a portion of the received current passes from the line through the galvanometer (or Morse), direct to earth through the rheostat B, and another portion by C, A, and B, the branches C and A acting really as a shunt on the galvanometer.

It will be seen that with the bridge arrangement the ordinary apparatus, needle, Morse, or relay can be used without alteration, but as far as the writer's experience is concerned, the double-winding or differential method is preferable, especially in difficult cases.

When the circuit exceeds about 100 miles, and when it contains cable or underground wire, it is found, especially in very dry weather, that however perfectly the resistances are adjusted, the balance is disturbed by the act of making or breaking contact, although signals are correctly received when the key remains depressed. The outgoing current has no effect on the relay while the key is depressed, but when battery contact is made or broken, the armature moves so as to record a dot at the sending station.

This is due to the static discharge from the line, and must be counteracted by making the capacity of the artificial line or rheostat equal to that of the actual line by means of condensers. When the cable exceeds a few miles in length, its charge and discharge occupy a longer time than is required for the charge and discharge of the condenser, and it is necessary to retard the action of the latter, dividing the plates into several groups, introducing resistance between the groups. The more evenly the induction is distributed over the artificial line formed by the condensers and resistance coils, the more perfect is the compensation.

As the rheostat (the artificial line) forms a derived circuit for the battery current, the resistance of the battery must be low

DOUBLE CURRENT SYSTEM

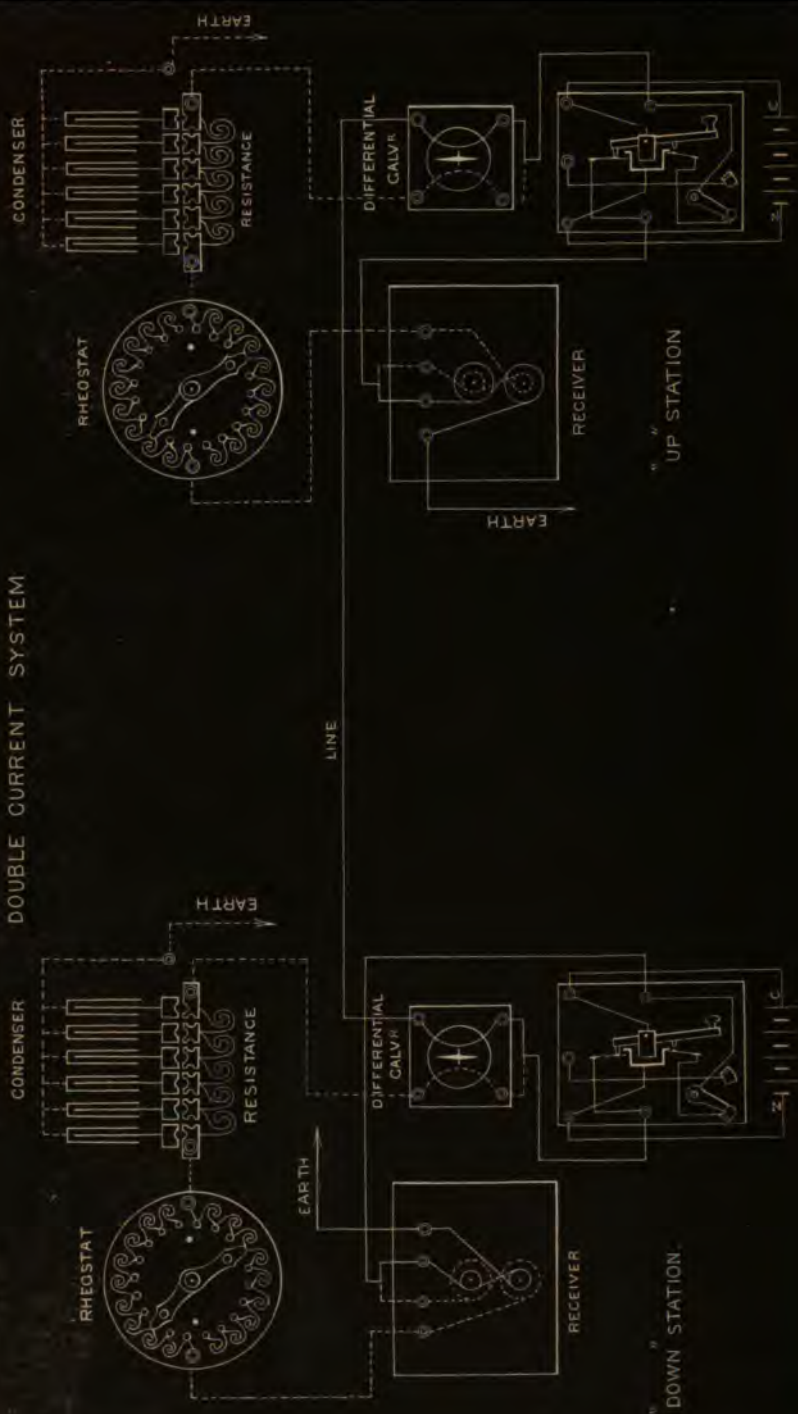
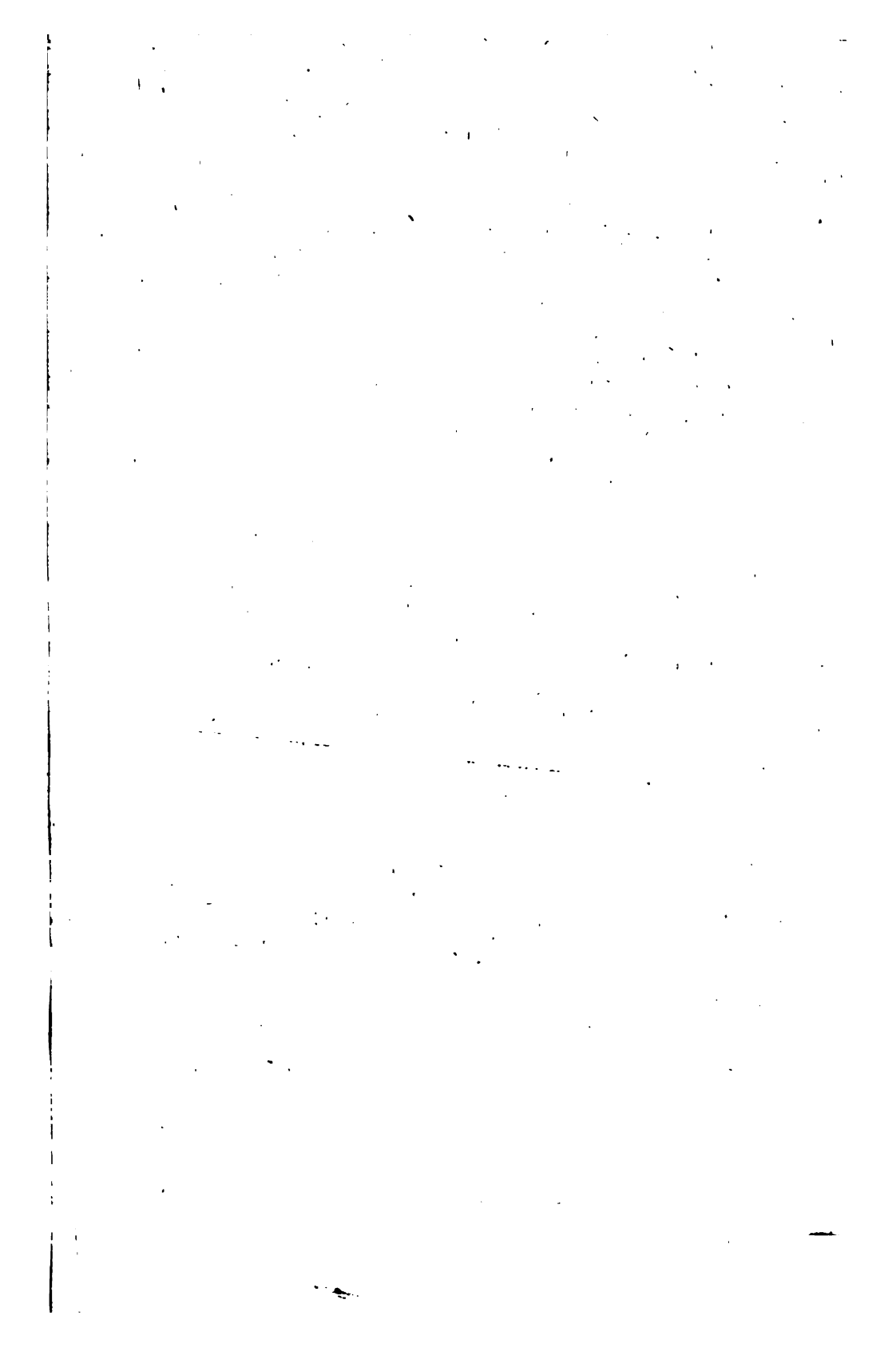


FIG. 139.



and as a rule the number of cells required is greater than in the single or ordinary system. As the resistance of the line constantly varies from the effect of damp and other causes affecting insulation sometimes fifty per cent. during the day, the rheostat is made adjustable. The capacity of the condenser is also made variable, for the capacity of the line varies with the insulation.

As it is necessary that the resistance of the circuit shall be uniform at all times, an arrangement is required in the key to compensate for the resistance of the battery when the battery contact is open; if this is not attended to, the circuit for incoming currents when the key is pressed, is divided at the key between battery and rheostat, but when the key is at rest the circuit is through the rheostat only. A resistance equal to that of the battery is therefore placed between the back-stop of the key and earth.

This compensation, however, hardly appears to be absolutely necessary for short circuits, if the play of the key is very small. It is not necessary under the double current system, as the battery is always in circuit, and the resistance uniform in all positions of the key.

The rheostat should have a range equalling that of the extreme difference in resistance of the line as affected by weather, and for the finer final adjustments the coils may vary from 400 to 40 by differences, one from the other, of 40 ohms. No lower resistance than 40 ohms is required.

The condenser in like manner must be large enough to balance the capacity of the line in the finest weather. The smallest set of plates may be equal to $\frac{1}{4}$ microfarad.

Fig. 139 shows the double current duplex system employed by the Post Office. The keys are of the ordinary form, but with as small a break as possible. The receiver is that used in Wheatstone's automatic system, which requires no relay, and is wound differentially; the rheostat coils are arranged in a circle, and contact is made through two levers resembling the hands of a watch, one of which is connected to the higher, the other to the lower resistances.

The condensers are provided with commutators, by means of which their capacity is adjusted and resistance introduced

between the several plates for the purpose of retarding the discharge.

The differential galvanometer is used for balancing the line and rheostat.

RULES FOR WORKING DUPLEX CIRCUITS.

The resistances at each end should be first approximately adjusted to the length of the line, so that no signals are made on the home instrument when the key is worked. One station should then send alphabets or words to the other, an irregular succession of signals being preferable to a repetition of the same letter.

The station who is receiving should depress his key, and see if the received signals are affected; if this is the case the balance is not perfect. Should the depression of the key cause the received signals to run together, it is a proof that too much current goes out to line, and too little through the resistance coils to the earth. The resistance in the rheostat must in this case be decreased, until the depression of the key has no effect on the signals.

Should the signals have a tendency to miss, and the dots be too small or lost altogether when the key is depressed, it is a proof that too much current goes out through the rheostat coils. The resistance in the rheostat must be increased, until the balance is obtained, and no effect is produced on the signals by moving the key.

When one station has regulated and obtained a balance, he should then send alphabets or words to the other station, who will regulate in like manner.

On lines where a condenser is used the following rules may be observed:—

When, after obtaining a balance in the ordinary way by means of the resistance coils, the received signals break up on working the key, but are good when the key is simply elevated or depressed, it is a proof that the condenser is not properly balanced, either that the number of plates is too large or too small, but more generally the latter.

Set the relay somewhat delicately, and note if a dot appears on the paper on depressing the key; if so it is a proof that the condenser is too small, and the number of plates must be increased, until the dot disappears on the depression of the key. If no dot appears on depressing the key, and yet the received signals are broken, the condenser is too large. Let the distant station depress his key, which will cause an unbroken line to appear on the paper; if now a depression of the home key cause a momentary break in this line, it is a proof that there are too many plates of the condenser in use, their number must be reduced, until a depression of the key has no effect in breaking the line formed by the distant station.

In any polarized arrangement, such as a Wheatstone receiver or Siemens' relay, the appearance of one's own signals on the paper when sending, is a proof that too much current is being sent out to line, and that the resistance in the rheostat requires decreasing; but in a direct writer, or any similar arrangement where an ordinary electro-magnet with soft iron armature is used, the case is different; for an excess of current, whether going out to line or through the rheostat circuit, will attract the armature, and there is nothing, save experience, to indicate whether the resistance in the rheostat must be increased or diminished, so that the resistance will have to be altered until the outgoing current ceases to actuate the home magnet.

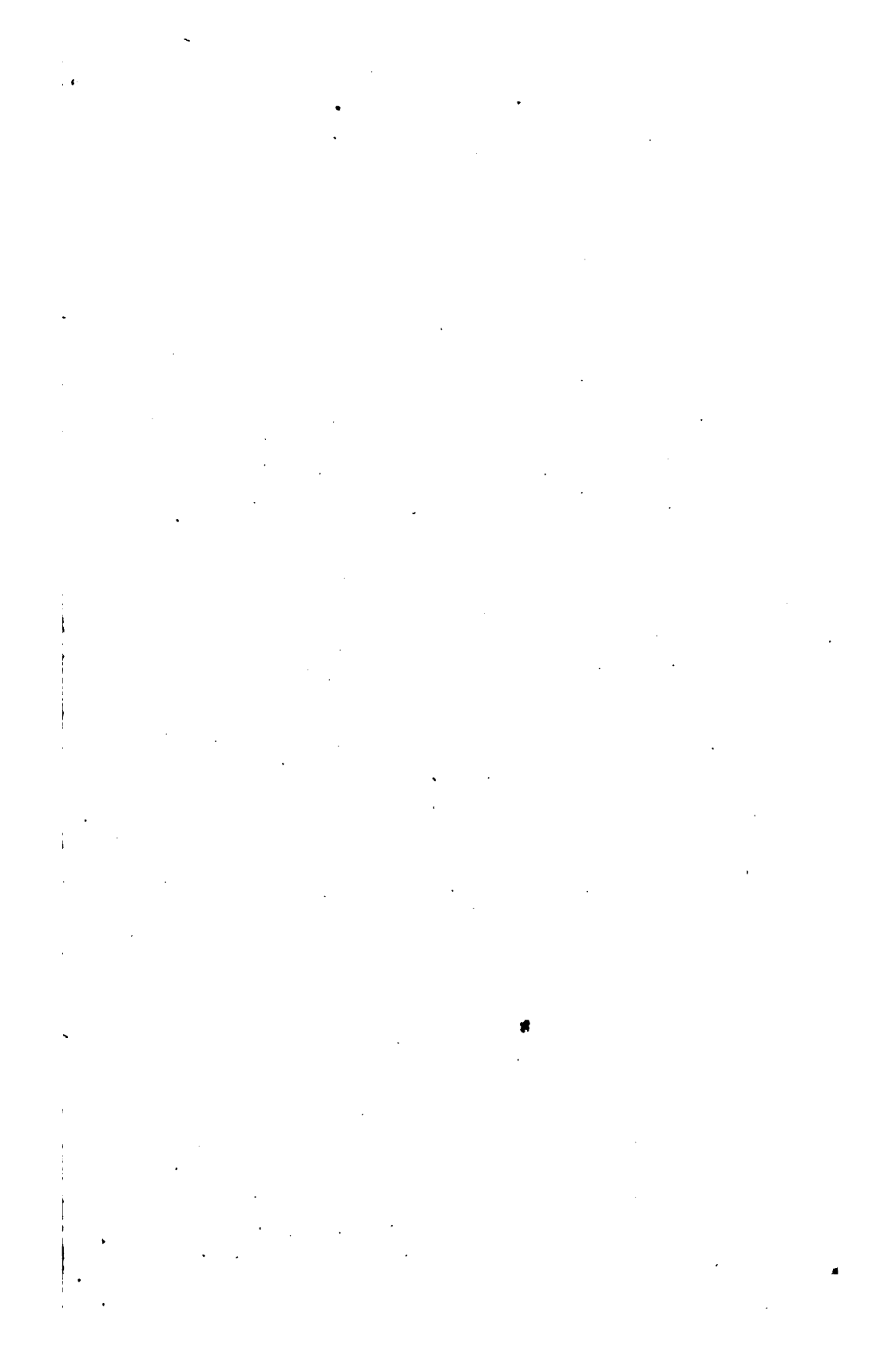
Mr. Stearns has favoured the Author with the following full description of his system.

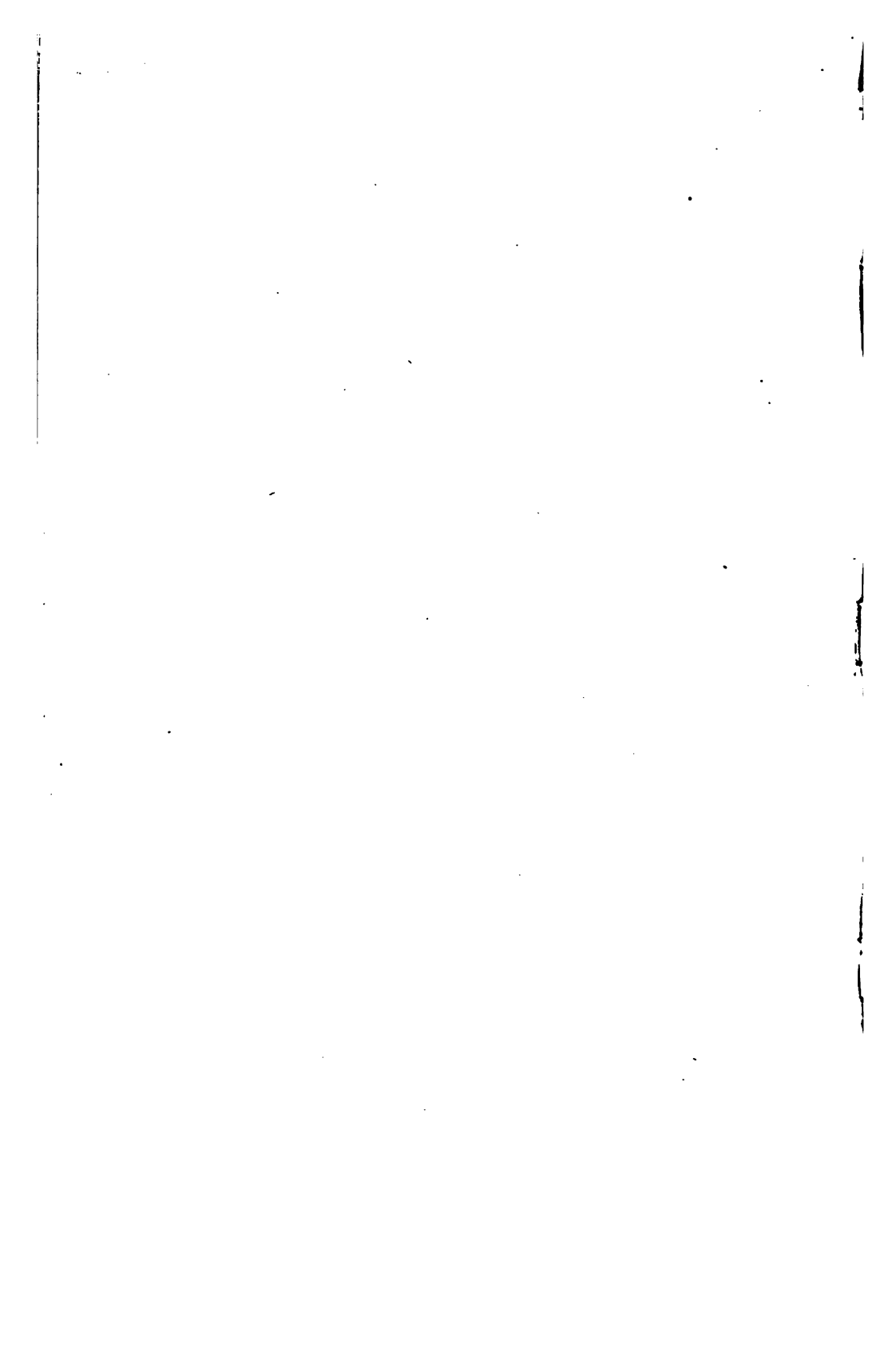
STEARNS' SYSTEM.

The Differential method.—A and A', Fig. 140, represent the two terminal stations of a line. The line battery B at station A has its positive pole to the line, and its negative pole to the earth, while the battery B' at station A' has its negative pole to the line, and its positive pole to the earth. R and R' are the receiving-magnets or relays, the helices of which are wound with two wires of the same resistance and having an equal number of convolutions. These two wires are wound

upon the helix at the same time, and consequently run side-by-side throughout the magnet. The *outer* end of one of these wires is connected to the line-wire, and the *inner* end of the other wire is connected to one terminal of the rheostat x , the other terminal of which is to earth. The remaining two ends of the relay wires are joined together at j and connected to the spring s , which is carried by, but insulated from, the lever l of the *transmitter* T , this lever is connected to earth by a wire in which is placed a resistance x equal to that of the battery B . When the key is open the spring s and lever l are in contact, and together form a part of the circuit from the line to the earth. The lever l is provided with an armature, and is actuated by an electro-magnet, local battery, and single-current key. The sounders, ink-writers, or other instruments for indicating or recording the received signals, are operated by local batteries in the usual manner. The positive pole of the battery B is connected to the contact screw t . C is a condenser, one pole of which is connected to the wire joining the relay and the rheostat, while the other pole is to earth. The rheostats x and x' are capable of adjustment, and the resistance of each should *theoretically* be equal to the resistance of the line-wire added to that of the battery and one wire of the relay at the other station. Practically this is seldom or never found to be the best working balance, owing to a variety of causes, such as the leakage of the current to earth, the cross-leakage or *contact* from other wires, &c. The best working adjustment is obtained by closing the key at either station, and observing the character of the signals received from the other station. If the signals are too *light*, the resistance of the rheostat must be *increased*; if they are too heavy, the resistance must be *decreased*.

The operation of the apparatus, after being adjusted, is as follows:—If the finger key at station A be depressed, the circuit of the local battery is closed through the magnet T , and the armature is attracted, thereby moving the opposite end of lever l so as to bring the spring s in contact with the screw t after removing it from its previous contact with the lever l . The current from the battery B will now flow through screw t





and spring *s* to the junction of the two relay wires at *J*, where it will divide into two equal portions, one half of it going through one wire of relay *R* to and over the line to station *A'*, thence through one of the wires of relay *R'* to the junction *J'*, thence through spring *s'*, lever *l'*, and resistance coil *x'*, to the earth. The other portion of the current flows from the junction *J* in an opposite direction through the other wire of relay *R*, and thence through rheostat *x* to the earth. The relay *R* being thus acted upon simultaneously by equal and opposing currents, will remain entirely unaffected. The distant relay *R'*, however, will be affected by the current passing over the line and through *one only of its wires* to the earth, and will produce signals corresponding to the movements of the key at station *A*.

If now the key at station *B* be depressed, a similar action takes place: the current passes from battery *B'* through the screw *t'*, spring *s'* to junction *J'*, where it divides, one-half flowing through one wire of relay *R'* and over the line, combining with the current from station *A*, and the other half returning to the earth through the other wire of relay *R'* and rheostat *x'*. Thus each relay is unaffected by the current from the battery at its own station, or the *outgoing current*, but responds to the *incoming current*, or current from the battery at the other station.

It is a matter of importance that the resistance presented both to the outgoing and incoming currents at each station be the same whatever may be the position of the keys, or transmitter levers, at either station. To secure this, coils *x* and *x'* are placed in the wires connecting the levers *l*, *l'* with the earth, and the resistance of these coils is made equal to that of the batteries at their respective stations. For example, the resistance from *J* through *s*, *l* and *x* to earth when the key is open, is the same as from *J* through *s*, *t* and battery *B* to earth, when the key is closed. If this equalization be not attended to, the movements of the key at either station will disturb both the magnetic and the static balances at the other station.

Use and adjustment of the condenser.—In signalling through submarine cables, or land lines of considerable length, the *return*

charge arising from static induction has heretofore been found to interfere with the operation of the instruments. To remedy this difficulty the condensers C and C' are employed, being connected in the compensating circuit. If the static capacity of the condenser, and the time and distribution of its discharge be adjusted to those of the line or cable, it compensates for and removes the effect of static induction. Whatever static charge may be induced upon the line or cable by the outgoing current, the equal current going to earth through X will induce a corresponding charge in the condenser C , and both being discharged through the separate wires of the relay R in opposite directions at the same time, produce no effect upon the relay; the charge from the condenser neutralizing the effect of that from the line.

If the line or cable be of considerable length, it will receive and give up its charge more slowly than the condensers, and although the amount of the charge and discharge from each may be equal, a true working balance will not be obtained unless the action of the condensers can be in some way retarded. This result is accomplished by inserting small electro-magnet coils between the condenser and the instrument, and if several small condensers are used, instead of one large one, then electro-magnets are inserted between the several condensers at $r^1 r^2 r^3$ &c. (Fig. 140). These coils are provided with cores, which may be partially or wholly withdrawn, in order to vary the amount of magnetism imparted, and consequently the amount of retardation produced. The resistance of these coils seems to be a matter of little importance, and they are not usually over 25 ohms each; and it has been found that no amount of simple resistance will produce the same result as the induction coils. Simple resistance reduces the quantity of charge, without materially lengthening it or modifying its quality. It will be seen that the discharge from each condenser is retarded more than that from the one before it, thus c^1 is retarded by r^1 , c^2 by r^2 and r^1 , and so on; the discharges from all are thus made to resemble that from the line or cable, not only in amount, but in the time of charge and discharge, and also in the distribution of the charge and discharge during the time.

The effect of these coils is, first, to absorb, as it were, a por-

tion of the initial discharge current from the condenser by becoming themselves magnetic, or, in other words, a portion of the current is prevented from acting upon the relay by being *converted into magnetism*; second, the magnetism of these coils is, a little later, re-converted into current, and adds to the original current, which has by that time become weakened, or continues the current after the original current has ceased altogether.

A condenser of exactly the desired capacity is not always readily obtained, and, therefore, some means of adjusting its effects upon the receiving instrument is necessary. When the capacity of the condenser is greater than that of the line or cable, its effects upon the receiving relay, R (Fig. 140), can be reduced by including a portion of the resistance of the compensating circuit between the relay and the point at which the condenser is attached to the rheostat X. Let us suppose that the capacity of the condenser C be greater than that of the line, and that when it is connected directly to the instrument, as in the cut, the excess of its charge or discharge over that of the line disturbs the relay R. If it be connected at an intermediate point of X, instead of the point nearest the relay, it will receive a smaller charge than before, in consequence of the tension of the current having become reduced by the resistance introduced between the relay and the condenser; and a greater proportion of this diminished charge will go to earth through the rheostat. The condenser will, in fact, have been *shunted* by a *decreased* resistance. Thus a condenser of any capacity, greater than that of the line, may be employed.

In case the capacity of the condenser is less than that of the line or cable, resistance may be inserted between the relay and the *line*, the resistance of the compensating circuit being correspondingly increased, and the condenser connected, as shown in the cut, close to the relay. The line will now receive a smaller charge than before, because the tension of the current has become reduced by the resistance before reaching the line; while the condenser will take a greater charge than before, because the resistance of the compensating circuit has been increased *beyond* the point at which it is attached to the con-

denser, or in other words, the condenser is now *shunted* by an *increased* resistance. If the resistance introduced between relay and line be made considerable, the battery power may be increased, which will cause the condenser to take still higher charge. By this means, a condenser of much smaller capacity than the line may be used.

Static discharge can be compensated by the use of an induction coil, or a series of electro-magnets, instead of the condenser.

The Bridge Method.—Fig. 141 shows a modification of the system, or more properly a different method, involving the principle of the Wheatstone Bridge. By this method the single or double current Morse, the Hughes, the Wheatstone Automatic, the Mirror, or any other form of receiving instrument, may be used without modification.

The relay or other receiving instrument (Station A) is placed in the *bridge wire* $m\ n$ between the two arms u and v of the bridge. The outgoing current divides at J , one half going through the resistance coil v to terminal n , thence to and through the rheostat x to the earth; the other half going through the resistance coil u to terminal m , and thence over the line to Station A', where it divides at m' , one portion going through the *bridge wire* and receiving instrument R' to n' , thence through the resistance coil v' to J' , thence by the spring s' , lever l' , and coil x' to the earth; the other portion going through coil u' to J' , where it joins that portion of the current passing through the receiving instrument, thence to earth as already described. By varying the resistance of the arms of the bridge, u' and v' , any desired proportion of the arriving current may be made to pass through the receiving instrument R' ; and although in practice only about one-half the current is thus utilized, that *half acts upon all the wire of the receiving instrument* instead of upon only half the wire, as in the differential method. Of course, when the resistance u is in the same proportion to that of the line and apparatus at Station A', as the resistance of v is to that of rheostat x , no part of the outgoing current will pass through the receiving instrument, and in this respect it differs entirely from the differential method, where the receiving

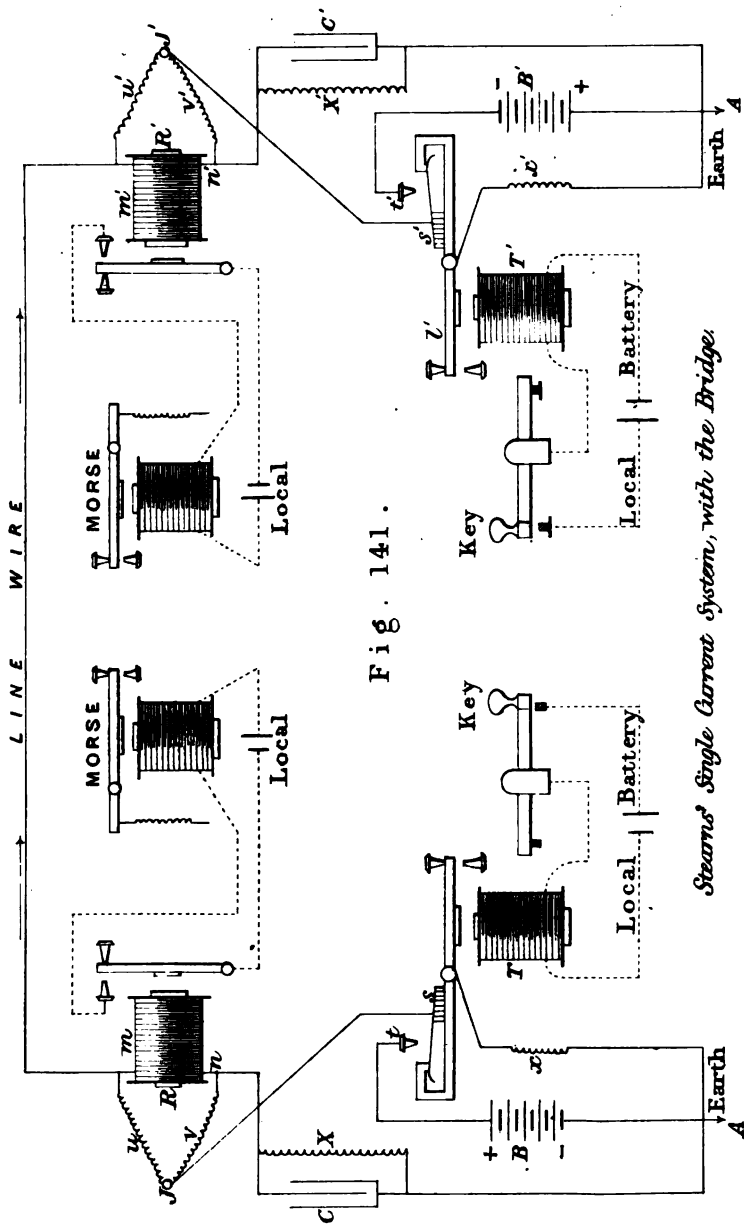
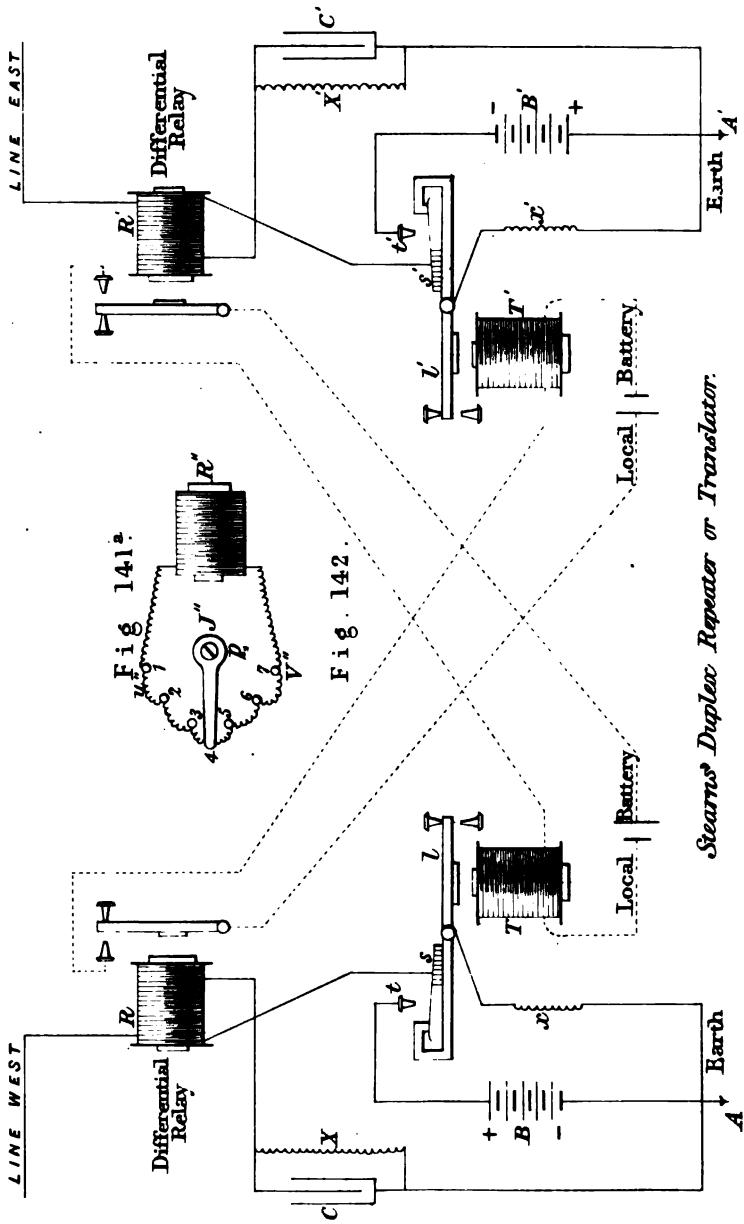


Fig. 141.

Stearns' Single Current System, with the Bridge.



Searns' Duplex Repeater or Translator.

instrument is prevented from working—not by an entire absence of current but by the presence of two equal and opposing currents.

A convenient device for adjustment in this method, and one which enables inexperienced clerks to manage, though they may not understand the principles of the system, consists in varying the relative proportions of u and v by shifting the point J'' to one side or the other, to compensate for the changing resistance of the line (Fig. 141 *a*). For this purpose resistance of the arms of the bridge u'' and v'' , or a part of each, is divided into several small and equal resistances, 1, 2, 3, 4, &c.; and the moveable arm p is so arranged that it can be moved towards 1 or 7, increasing the resistance of u'' and decreasing that of v'' , or *vice versa*, as desired. The rest of the connections are the same as in the differential method.

Repeater.—Fig. 142 shows the manner of coupling two sets of apparatus together at an intermediate station, for the purpose of translating or repeating from one circuit to another. The only modification consists in conducting the local circuit from each relay to the local magnet of the transmitter on the opposite side, *i.e.* the *eastern* relay operates the transmitter on the *western* side. When an unpolarised relay, in which the armature is held back by a spring, is used, there is considerable advantage in employing a shunt to short circuit the relay *after* it has done its work of closing the local circuit, for the purpose of cutting off the line current. This permits the armature spring of the relay to be very considerably slackened, as it will not have to oppose the force of a prolongation of the line current, nor will the iron become so strongly magnetized.

Dots will be firmer, and *sticking* will be prevented, which would otherwise occur with a weak spring.

The shunt does not appear to be advantageous when applied to a *polarized* relay, where a spring is not used.

The shunt is placed between the line and the rheostat terminals of the relay, and is closed by the lever of the Morse or Sounder, as shown in Fig. 143.

In some cases it is better to prolong the contact of the Morse lever by a spring, as in Fig. 121 (p. 257), so as to keep the relay

shunted for a longer time than when a dead contact is used.
(*Stearns.*)

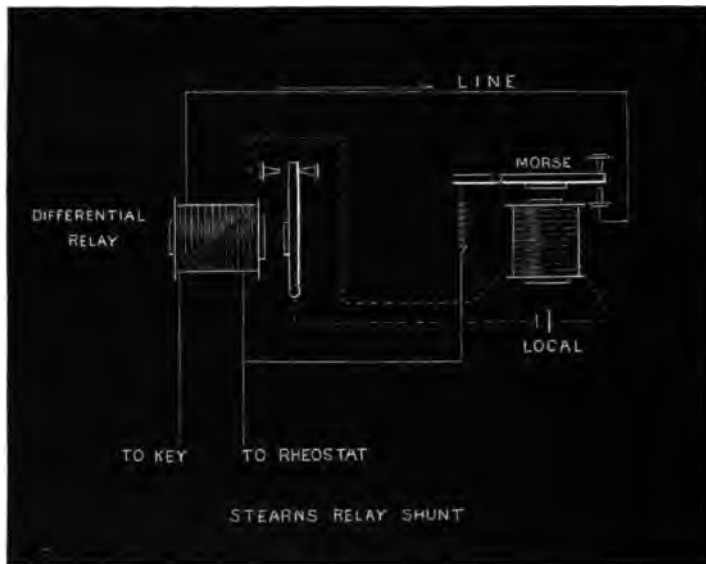


FIG. 143.

The continuous current system is applicable to the Duplex. The method has been successfully applied by the Engineer of the Telegraphs of the Madras Railway. He states:—

“The general arrangement will be understood from Fig. 144, in which A and B are two stations, and L is the line between them, b and b' are two equal batteries with the same pole permanently to earth in each case; r and r' are adjustable resistances, i and i' are the coils of the receiving instrument, the part of the coil i having say ten times as many convolutions as i' , and those of r and r' having also the same proportion between them. At the junctions between i and i' and between i and i' , the wire of the instrument is joined to one terminal of a key, the other terminal being connected with earth.

“Let us first suppose the insulation of the line to be perfect. So long as neither key is pressed the two batteries oppose and neutralize each other, so that there is no current flowing from

either. Let us press the key at A. If the resistance r be properly adjusted the two batteries will neutralize each other as regards the instrument at A, whereas at B the whole of the current from b' will flow through the instrument at B, causing a signal accordingly. When the key at B is pressed matters are simply reversed; while if both keys are pressed, each battery acts locally through the resistance coils, and the wires i and i' of the instruments, and both instruments are worked.

"The object of the resistance r is so to adjust the force of the current from the battery b , that acting through the small number of convolutions i it may balance and counteract that from the battery b' when the key at A is pressed, and *vice versa*. Suppose, for instance, that the ratio between the internal resist-

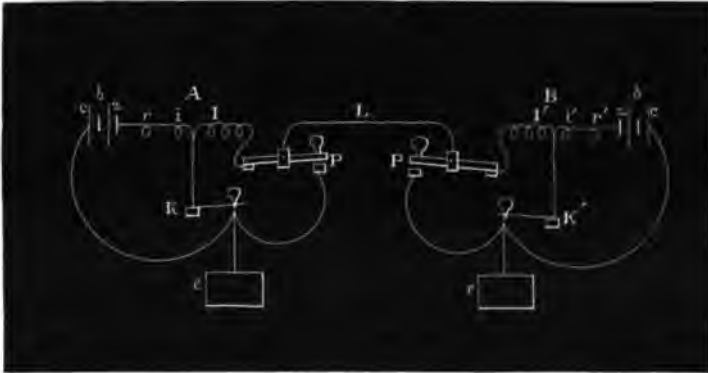


FIG. 144.

ance of b together with r , is to the resistance of the line and apparatus at B, as 1 is to 10; and further, suppose that the magnetic effect of i is to that of i' , as 1 to 10, then it is manifest that when K is pressed the instrument at A will be unaffected, for though the current from b is ten times as strong as that from b' , yet it acts at a disadvantage, having only $\frac{1}{10}$ th as many convolutions to act through as that from b' .

"We have seen that when one key (say that at A) only is pressed, the current from the distant station acts through the whole coil of the instrument there, it produces a signal therefore which is fully as powerful as the signals in ordinary or

single sending. Its action on the instrument at A, though neutralized by the battery acting locally there, is only reduced by $\frac{1}{11}$ th, that is it acts through $\frac{10}{11}$ ths of the convolutions of the instrument. Now when the key at B is pressed, the force with which the battery at A acts on the instrument at A is equal to the force it previously balanced, and that we have seen is $\frac{10}{11}$ ths of the full force of the current as utilized in single sending.

"The same reasoning applies to the action of the battery acting locally at B. The loss of force therefore in the case above alluded to is only $\frac{1}{11}$ th instead of $\frac{1}{2}$ as in the differential method previously described.

"Next let us suppose the insulation of the line to become defective. The leakage will cause a current to flow out through each instrument tending to produce a signal. All we have to do to remedy this is to give the instrument a bias against making a signal, equal and opposite to the effect produced by the leakage current. With most instruments, especially with the polarized relays now almost universally employed, this is done by the ordinary adjustment of the instrument, with which operators are already familiar. Thus instead of having continually to adjust the balancing resistance as in the differential method, we have merely slightly to alter the position of the contact points in the polarized relay, or the tension of the spring in the old form of electro-magnet relay or in direct working instruments."

The compensation for static discharge is effected by means of induction coils.

NOTE.

Referring to page 185, it should have been there stated that the insulation of a line should never be allowed to fall below 200,000 ohms per mile in wet weather.

TABLES.

TABLE I.

SQUARES AND LOGARITHMS OF NUMBERS FROM 1 TO 1049.

LOGARITHMS are artificial numbers employed to facilitate calculations.

Every logarithm consists of two parts, separated by a decimal point; the latter, or decimal portion, only is given in the tables. The former portion or *index* is, in the case of whole numbers, or whole numbers combined with decimal fractions, one less than the number of figures in the corresponding whole numbers. Thus, the index of the logarithm of 2 will be 0; the index of the logarithm of 20, 1, and so on. These indices must always be supplied.

Multiplication by logarithms.—The sum of the logarithms of two numbers equals the logarithm of their product.
Example:—

$$\begin{array}{rcl} \text{Multiply 25 by 36. Log. } 25 & = & 1.39794 \\ & & \text{,, } 36 = 1.55630 \\ & & \hline & & 2.95424 = \text{log. } 900. \\ & & \hline \end{array}$$

Division by logarithms.—From the logarithm of the dividend subtract the logarithm of the divisor, the remainder will be the logarithm of the quotient. Example:—

$$\begin{array}{r} \text{Divide 900 by 36. Log. 900} = 2.95424 \\ \text{„ 36} = 1.55630 \\ \hline 1.39794 = \log. 25. \end{array}$$

Rule of three by logarithms.—Add together the logarithms of the 2nd and 3rd terms, and subtract the logarithm of the 1st term. Example:—

$$\begin{array}{r} \text{Find a 4th proportional to 36, 25, and 180.} \\ \text{Log. 25} = 1.39794 \\ \text{„ 180} = 2.25527 \\ \hline 3.65321 \\ \text{„ 36} = 1.55630 \\ \hline 2.09691 = \log. 125. \end{array}$$

Involution by logarithms.—Multiply the logarithm of the number by the index of the required power. Example:—

$$\begin{array}{r} \text{Find the cube or 3rd power of 8.} \\ \text{Log. 8} = 0.90309 \\ \text{3} \\ \hline 2.70927 = \log. 512. \end{array}$$

Evolution by logarithms.—Divide the logarithm of the number by the index of the root required. Example:—

Find the cube root or 3rd root of 512.

$$\text{Log. 512} = 2.70927 \div 3 = 0.90309 = \log. 8.$$

From the foregoing examples it will be seen that the addition and subtraction of logarithms give results equivalent to the mul-

multiplication and division of their corresponding numbers ; while the long and difficult arithmetical operations of raising powers and extracting roots are accomplished by means of simple multiplication and division.

To find the logarithm of a number of four places, from Table I.—Find the logarithm of the first three figures in the table, and take the difference between that logarithm and the next following logarithm. Multiply this difference by the fourth figure of the number, and add one-tenth of the product to the logarithm of the first three figures. Example:—Required the logarithm of 1344. The log. of 134 is 12710, that of 135 is 13033, and the difference 323. Then $\frac{323 \times 4}{10} = 129$, which added to 12710 = 12839. The logarithm of 1344 will, therefore, be 3·12839, when the proper index has been supplied.

The contraction *log.* indicates the common logarithm as given in the table.

Log. *e* indicates Napier's system of logarithms ; it is sometimes written *log. Nap.*, or *log. nat.* a contraction for *natural* logarithm, or *log. hyp.* for *hyperbolical* logarithm. The logarithms on this system are proportional to the common logs., which may be converted into the Napierian system by being multiplied by 2·3.

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
1	1	00000	50	2500	69897	100	10000	00000
2	4	30103	1	2601	70757	1	10201	00432
3	9	47712	2	2704	71600	2	10404	00860
4	16	60206	3	2809	72427	3	10609	01284
5	25	69897	4	2916	73239	4	10816	01703
6	36	77815	5	3025	74036	5	11025	02119
7	49	84510	6	3136	74819	6	11236	02530
8	64	90309	7	3249	75587	7	11449	02938
9	81	95424	8	3364	76343	8	11664	03342
			9	3481	77085	9	11881	03743
10	100	00000	60	3600	77815	110	12100	04139
1	121	04139	1	3721	78533	1	12321	04532
2	144	07918	2	3844	79239	2	12544	04922
3	169	11394	3	3969	79934	3	12769	05308
4	196	14613	4	4096	80618	4	12996	05690
5	225	17609	5	4225	81291	5	13225	06070
6	256	20412	6	4356	81954	6	13456	06446
7	289	23045	7	4489	82607	7	13689	06818
8	324	25527	8	4624	83251	8	13924	07188
9	361	27875	9	4761	83885	9	14161	07555
20	400	30103	70	4900	84510	120	14400	07918
1	441	32222	1	5041	85126	1	14641	08278
2	484	34242	2	5184	85733	2	14884	08636
3	529	36173	3	5329	86332	3	15129	08990
4	576	38021	4	5476	86923	4	15376	09342
5	625	39794	5	5625	87506	5	15625	09691
6	676	41497	6	5776	88081	6	15876	10037
7	729	43136	7	5929	88649	7	16129	10380
8	784	44716	8	6084	89209	8	16384	10721
9	841	46240	9	6241	89763	9	16641	11059
30	900	47712	80	6400	90309	130	16900	11394
1	961	49136	1	6561	90848	1	17161	11727
2	1024	50515	2	6724	91381	2	17424	12057
3	1089	51851	3	6889	91908	3	17689	12385
4	1156	53148	4	7056	92428	4	17956	12710
5	1225	54407	5	7225	92942	5	18225	13033
6	1296	55630	6	7396	93450	6	18496	13354
7	1369	56820	7	7569	93952	7	18769	13672
8	1444	57978	8	7744	94448	8	19044	13988
9	1521	59106	9	7921	94939	9	19321	14301
40	1600	60206	90	8100	95424	140	19600	14613
1	1681	61278	1	8281	95904	1	19881	14922
2	1764	62325	2	8464	96379	2	20164	15229
3	1849	63347	3	8649	96848	3	20449	15534
4	1936	64345	4	8836	97313	4	20736	15836
5	2025	65321	5	9025	97772	5	21025	16137
6	2116	66276	6	9216	98227	6	21316	16435
7	2209	67210	7	9409	98677	7	21609	16732
8	2304	68124	8	9604	99123	8	21904	17026
9	2401	69020	9	9801	99563	9	22201	17319

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
150	22500	17609	200	40000	30103	250	62500	39794
1	22801	17898	1	40401	30320	1	63001	39967
2	23104	18184	2	40804	30535	2	63504	40140
3	23409	18469	3	41209	30750	3	64009	40312
4	23716	18752	4	41616	30963	4	64516	40483
5	24025	19033	5	42025	31175	5	65025	40654
6	24336	19312	6	42436	31387	6	65536	40824
7	24649	19590	7	42849	31597	7	66049	40993
8	24964	19866	8	43264	31806	8	66564	41162
9	25281	20140	9	43681	32015	9	67081	41330
160	25600	20412	210	44100	32222	260	67600	41497
1	25921	20682	1	44521	32428	1	68121	41664
2	26244	20951	2	44944	32633	2	68644	41830
3	26569	21219	3	45369	32838	3	69169	41995
4	26896	21484	4	45796	33041	4	69696	42160
5	27225	21748	5	46225	33244	5	70225	42324
6	27556	22011	6	46656	33445	6	70756	42488
7	27889	22272	7	47089	33646	7	71289	42651
8	28224	22531	8	47524	33846	8	71824	42813
9	28561	22789	9	47961	34044	9	72361	42975
170	28900	23045	220	48400	34242	270	72900	43136
1	29241	23300	1	48841	34439	1	73441	43297
2	29584	23553	2	49284	34635	2	73984	43457
3	29929	23805	3	49729	34830	3	74529	43616
4	30276	24055	4	50176	35025	4	75076	43775
5	30625	24304	5	50625	35218	5	75625	43933
6	30976	24551	6	51076	35411	6	76176	44091
7	31329	24797	7	51529	35602	7	76729	44248
8	31684	25042	8	51984	35793	8	77284	44404
9	32041	25285	9	52441	35983	9	77841	44560
180	32400	25527	230	52900	36173	280	78400	44716
1	32761	25768	1	53361	36361	1	78961	44871
2	33124	26007	2	53824	36549	2	79524	45025
3	33489	26245	3	54289	36735	3	80089	45179
4	33856	26482	4	54756	36921	4	80656	45332
5	34225	26717	5	55225	37107	5	81225	45484
6	34596	26951	6	55696	37291	6	81796	45637
7	34969	27184	7	56169	37475	7	82369	45788
8	35344	27416	8	56644	37658	8	82944	45939
9	35721	27646	9	57121	37840	9	83521	46090
190	36100	27875	240	57600	38021	290	84100	46240
1	36481	28103	1	58081	38202	1	84681	46389
2	36864	28330	2	58564	38381	2	85264	46538
3	37249	28556	3	59049	38561	3	85849	46687
4	37636	28780	4	59536	38739	4	86436	46835
5	38025	29003	5	60025	38917	5	87025	46982
6	38416	29226	6	60516	39093	6	87616	47129
7	38809	29447	7	61009	39270	7	88209	47276
8	39204	29666	8	61504	39445	8	88804	47422
9	39601	29885	9	62001	39620	9	89401	47567

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
300	90000	47712	350	122500	54407	400	160000	60206
1	90601	47857	1	123201	54531	1	160801	60314
2	91204	48001	2	123904	54654	2	161604	60423
3	91809	48144	3	124609	54777	3	162409	60530
4	92416	48287	4	125316	54900	4	163216	60638
5	93025	48430	5	126025	55023	5	164025	60745
6	93636	48572	6	126736	55145	6	164836	60853
7	94249	48714	7	127449	55267	7	165649	60959
8	94864	48855	8	128164	55388	8	166464	61066
9	95481	48996	9	128881	55509	9	167281	61172
310	96100	49136	360	129600	55630	410	168100	61278
1	96721	49276	1	130321	55751	1	168921	61384
2	97344	49415	2	131044	55871	2	169744	61490
3	97969	49554	3	131769	55991	3	170569	61595
4	98596	49693	4	132496	56110	4	171396	61700
5	99225	49831	5	133225	56229	5	172225	61805
6	99856	49969	6	133956	56348	6	173056	61909
7	100489	50106	7	134689	56467	7	173889	62014
8	101124	50243	8	135424	56585	8	174724	62118
9	101761	50379	9	136161	56703	9	175561	62221
320	102400	50515	370	136900	56820	420	176400	62325
1	103041	50650	1	137641	56937	1	177241	62428
2	103684	50785	2	138384	57054	2	178084	62531
3	104329	50920	3	139129	57171	3	178929	62634
4	104976	51054	4	139876	57287	4	179776	62736
5	105625	51188	5	140625	57403	5	180625	62839
6	106276	51322	6	141376	57519	6	181476	62941
7	106929	51455	7	142129	57634	7	182329	63043
8	107584	51587	8	142884	57749	8	183184	63144
9	108241	51719	9	143641	57864	9	184041	63246
330	108900	51851	380	144400	57978	430	184900	63347
1	109561	51983	1	145161	58092	1	185761	63448
2	110224	52114	2	145924	58206	2	186624	63548
3	110889	52244	3	146689	58320	3	187489	63649
4	111556	52375	4	147456	58433	4	188356	63749
5	112225	52504	5	148225	58546	5	189225	63849
6	112896	52634	6	148996	58659	6	190096	63949
7	113569	52763	7	149769	58771	7	190969	64048
8	114244	52892	8	150544	58883	8	191844	64147
9	114921	53020	9	151321	58995	9	192721	64246
340	115600	53148	390	152100	59106	440	193600	64345
1	116281	53275	1	152881	59218	1	194481	64444
2	116964	53403	2	153664	59329	2	195364	64542
3	117649	53529	3	154449	59439	3	196249	64640
4	118336	53656	4	155236	59550	4	197136	64738
5	119025	53782	5	156025	59660	5	198025	64836
6	119716	53908	6	156816	59769	6	198916	64933
7	120409	54033	7	157609	59879	7	199809	65031
8	121104	54158	8	158404	59988	8	200704	65128
9	121801	54282	9	159201	60097	9	201601	65225

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
450	202500	65321	500	250000	69897	550	302500	74036
1	203401	65418	1	251001	69984	1	303601	74115
2	204304	65514	2	252004	70070	2	304704	74194
3	205209	65610	3	253009	70157	3	305809	74272
4	206116	65705	4	254016	70243	4	306916	74351
5	207025	65801	5	255025	70329	5	308025	74429
6	207936	65896	6	256036	70415	6	309136	74507
7	208849	65992	7	257049	70501	7	310249	74585
8	209764	66086	8	258064	70586	8	311364	74663
9	210681	66181	9	259081	70672	9	312481	74741
460	211600	66276	510	260100	70757	560	313600	74819
1	212521	66370	1	261121	70842	1	314721	74896
2	213444	66464	2	262144	70927	2	315844	74974
3	214369	66558	3	263169	71012	3	316969	75051
4	215296	66652	4	264196	71096	4	318096	75128
5	216225	66745	5	265225	71181	5	319225	75205
6	217156	66838	6	266256	71265	6	320356	75282
7	218089	66932	7	267289	71349	7	321489	75358
8	219024	67024	8	268324	71433	8	322624	75435
9	219961	67117	9	269361	71517	9	323761	75511
470	220900	67210	520	270400	71600	570	324900	75587
1	221841	67302	1	271441	71684	1	326041	75664
2	222784	67394	2	272484	71767	2	327184	75740
3	223729	67486	3	273529	71850	3	328329	75815
4	224676	67578	4	274576	71933	4	329476	75891
5	225625	67669	5	275625	72016	5	330625	75967
6	226576	67761	6	276676	72098	6	331776	76042
7	227529	67852	7	277729	72181	7	332929	76117
8	228484	67943	8	278784	72263	8	334084	76193
9	229441	68033	9	279841	72345	9	335241	76268
480	230400	68124	530	280900	72427	580	336400	76343
1	231361	68214	1	281961	72509	1	337561	76418
2	232324	68305	2	283024	72591	2	338724	76492
3	233289	68395	3	284089	72673	3	339889	76567
4	234256	68484	4	285156	72754	4	341056	76641
5	235225	68574	5	286225	72835	5	342225	76715
6	236196	68664	6	287296	72916	6	343396	76790
7	237169	68753	7	288369	72997	7	344569	76864
8	238144	68842	8	289444	73078	8	345744	76938
9	239121	68931	9	290521	73159	9	346921	77011
490	240100	69020	540	291600	73239	590	348100	77085
1	241081	69108	1	292681	73320	1	349281	77159
2	242064	69196	2	293764	73400	2	350464	77232
3	243049	69285	3	294849	73480	3	351649	77305
4	244036	69373	4	295936	73560	4	352836	77379
5	245025	69460	5	297025	73640	5	354025	77452
6	246016	69548	6	298116	73719	6	355216	77525
7	247009	69636	7	299209	73799	7	356409	77597
8	248004	69723	8	300304	73878	8	357604	77670
9	249001	69810	9	301401	73957	9	358801	77743

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
600	360000	77815	650	422500	81291	700	490000	84510
1	361201	77887	1	423801	81358	1	491401	84572
2	362404	77960	2	425104	81425	2	492804	84634
3	363609	78032	3	426409	81491	3	494209	84695
4	364816	78104	4	427716	81558	4	495616	84757
5	366025	78175	5	429025	81624	5	497025	84819
6	367236	78247	6	430336	81690	6	498436	84880
7	368449	78319	7	431649	81756	7	499849	84942
8	369664	78390	8	432964	81822	8	501264	85003
9	370881	78462	9	434281	81888	9	502681	85065
610	372100	78533	660	435600	81954	710	504100	85126
1	373321	78604	1	436921	82020	1	505521	85187
2	374544	78675	2	438244	82086	2	506944	85248
3	375769	78746	3	439569	82151	3	508369	85309
4	376996	78817	4	440896	82217	4	509796	85370
5	378225	78887	5	442225	82282	5	511225	85431
6	379456	78958	6	443556	82347	6	512656	85491
7	380689	79028	7	444889	82412	7	514089	85552
8	381924	79099	8	446224	82478	8	515524	85612
9	383161	79169	9	447561	82543	9	516961	85673
620	384400	79239	670	448900	82607	720	518400	85733
1	385641	79309	1	450241	82672	1	519841	85793
2	386884	79379	2	451584	82737	2	521284	85854
3	388129	79449	3	452929	82801	3	522729	85914
4	389376	79518	4	454276	82866	4	524176	85974
5	390625	79588	5	455625	82930	5	525625	86034
6	391876	79657	6	456976	82995	6	527076	86094
7	393129	79727	7	458329	83059	7	528529	86153
8	394384	79796	8	459684	83123	8	529984	86213
9	395641	79865	9	461041	83187	9	531441	86273
630	396900	79934	680	462400	83251	730	532900	86332
1	398161	80003	1	463761	83315	1	534361	86392
2	399424	80072	2	465124	83378	2	535824	86451
3	400689	80140	3	466489	83442	3	537289	86510
4	401956	80209	4	467856	83506	4	538756	86570
5	403225	80277	5	469225	83569	5	540225	86629
6	404496	80346	6	470596	83632	6	541696	86688
7	405769	80414	7	471969	83696	7	543169	86747
8	407044	80482	8	473344	83759	8	544644	86806
9	408321	80550	9	474721	83822	9	546121	86864
640	409600	80618	690	476100	83885	740	547600	86923
1	410881	80686	1	477481	83948	1	549081	86982
2	412164	80753	2	478864	84011	2	550564	87040
3	413449	80821	3	480249	84073	3	552049	87099
4	414736	80888	4	481636	84136	4	553536	87157
5	416025	80956	5	483025	84198	5	555025	87216
6	417316	81023	6	484416	84261	6	556516	87274
7	418609	81090	7	485809	84323	7	558009	87332
8	419904	81157	8	487204	84385	8	559504	87390
9	421201	81224	9	488601	84448	9	561001	87448

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
750	562500	87506	800	640000	90309	850	722500	92942
1	564001	87564	1	641601	90363	1	724201	92993
2	565504	87622	2	643204	90417	2	725904	93044
3	567009	87679	3	644809	90471	3	727609	93095
4	568516	87737	4	646416	90526	4	729316	93146
5	570025	87795	5	648025	90579	5	731025	93197
6	571536	87852	6	649636	90633	6	732736	93247
7	573049	87909	7	651249	90687	7	734449	93298
8	574564	87967	8	652864	90741	8	736164	93349
9	576081	88024	9	654481	90795	9	737881	93399
760	577600	88081	810	656100	90848	860	739600	93450
1	579121	88138	1	657721	90902	1	741321	93500
2	580644	88195	2	659344	90956	2	743044	93551
3	582169	88252	3	660969	91009	3	744769	93601
4	583696	88309	4	662596	91062	4	746496	93651
5	585225	88366	5	664225	91116	5	748225	93702
6	586756	88423	6	665856	91169	6	749956	93752
7	588289	88479	7	667489	91222	7	751689	93802
8	589824	88536	8	669124	91275	8	753424	93852
9	591361	88593	9	670761	91328	9	755161	93902
770	592900	88649	820	672400	91381	870	756900	93952
1	594441	88705	1	674041	91434	1	758641	94002
2	595984	88762	2	675684	91487	2	760384	94052
3	597529	88818	3	677329	91540	3	762129	94101
4	599076	88874	4	678976	91593	4	763876	94151
5	600625	88930	5	680625	91645	5	765625	94201
6	602176	88986	6	682276	91698	6	767376	94250
7	603729	89042	7	683929	91750	7	769129	94300
8	605284	89098	8	685584	91803	8	770884	94349
9	606841	89154	9	687241	91855	9	772641	94399
780	608400	89209	830	688900	91908	880	774400	94448
1	609961	89265	1	690561	91960	1	776161	94497
2	611524	89321	2	692224	92012	2	777924	94547
3	613089	89376	3	693889	92064	3	779689	94596
4	614656	89432	4	695556	92117	4	781456	94645
5	616225	89487	5	697225	92169	5	783225	94694
6	617796	89542	6	698896	92221	6	784996	94743
7	619369	89597	7	700569	92272	7	786769	94792
8	620944	89653	8	702244	92324	8	788544	94841
9	622521	89708	9	703921	92376	9	790321	94890
790	624100	89763	840	705600	92428	890	792100	94939
1	625681	89818	1	707281	92479	1	793881	94988
2	627264	89872	2	708964	92531	2	795664	95036
3	628849	89927	3	710649	92583	3	797449	95085
4	630436	89982	4	712336	92634	4	799236	95134
5	632025	90037	5	714025	92686	5	801025	95182
6	633616	90091	6	715716	92737	6	802816	95231
7	635209	90146	7	717409	92788	7	804609	95279
8	636804	90200	8	719104	92839	8	806404	95328
9	638401	90255	9	720801	92891	9	808201	95376

TABLE I.
SQUARES AND LOGARITHMS.

N.	Square.	Logarithm.	N.	Square.	Logarithm.	N.	Square.	Logarithm.
900	810000	95424	950	902500	97772	1000	1000000	00000
1	811801	95472	1	904401	97818	1	1002001	00043
2	813604	95521	2	906304	97864	2	1004004	00087
3	815409	95569	3	908209	97909	3	1006009	00130
4	817216	95617	4	910116	97955	4	1008016	00173
5	819025	95665	5	912025	98000	5	1010025	00217
6	820836	95713	6	913936	98046	6	1012036	00260
7	822649	95761	7	915849	98091	7	1014049	00303
8	824464	95808	8	917764	98136	8	1016064	00346
9	826281	95856	9	919681	98182	9	1018081	00389
910	828100	95904	960	921600	98227	1010	1020100	00432
1	829921	95952	1	923521	98273	1	1022121	00475
2	831744	95999	2	925444	98317	2	1024144	00518
3	833569	96047	3	927369	98363	3	1026169	00561
4	835396	96095	4	929296	98408	4	1028196	00604
5	837225	96142	5	931225	98453	5	1030225	00647
6	839056	96189	6	933156	98498	6	1032256	00689
7	840889	96237	7	935089	98543	7	1034289	00732
8	842724	96284	8	937024	98587	8	1036324	00775
9	844561	96331	9	938961	98632	9	1038361	00817
920	846400	96379	970	940900	98677	1020	1040400	00860
1	848241	96426	1	942841	98722	1	1042441	00902
2	850084	96473	2	944784	98767	2	1044484	00945
3	851929	96520	3	946729	98811	3	1046529	00987
4	853776	96567	4	948676	98856	4	1048576	01030
5	855625	96614	5	950625	98900	5	1050625	01072
6	857476	96661	6	952576	98945	6	1052676	01115
7	859329	96708	7	954529	98989	7	1054729	01157
8	861184	96755	8	956484	99034	8	1056784	01199
9	863041	96801	9	958441	99078	9	1058841	01241
930	864900	96848	980	960400	99123	1030	1060900	01284
1	866761	96895	1	962361	99167	1	1062961	01326
2	868624	96941	2	964324	99211	2	1065024	01368
3	870489	96988	3	966289	99255	3	1067089	01410
4	872356	97035	4	968256	99299	4	1069156	01452
5	874225	97081	5	970225	99344	5	1071225	01494
6	876096	97127	6	972196	99388	6	1073296	01536
7	877969	97174	7	974169	99432	7	1075369	01578
8	879844	97220	8	976144	99476	8	1077444	01620
9	881721	97266	9	978121	99520	9	1079521	01661
940	883600	97313	990	980100	99563	1040	1081600	01703
1	885481	97359	1	982081	99607	1	1083681	01745
2	887364	97405	2	984064	99651	2	1085764	01787
3	889249	97451	3	986049	99695	3	1087849	01828
4	891136	97497	4	988036	99739	4	1089936	01870
5	893025	97543	5	990025	99782	5	1092025	01912
6	894916	97589	6	992016	99826	6	1094116	01953
7	896809	97635	7	994009	99869	7	1096209	01995
8	898704	97681	8	996004	99913	8	1098304	02036
9	900601	97727	9	998001	99956	9	1100401	02077

TABLE II.
NATURAL SINES AND TANGENTS.

Deg.	Sine.	Tangent.	Deg.	Sine.	Tangent.	Deg.	Sine.	Tangent.
1	·017	·017	31	·515	·601	61	·874	1·80
2	·035	·035	32	·530	·625	62	·883	1·88
3	·052	·052	33	·544	·649	63	·891	1·96
4	·070	·070	34	·559	·674	64	·899	2·05
5	·087	·087	35	·573	·700	65	·906	2·14
6	·104	·105	36	·588	·726	66	·913	2·24
7	·122	·123	37	·602	·753	67	·920	2·35
8	·139	·140	38	·615	·781	68	·927	2·47
9	·156	·158	39	·629	·810	69	·933	2·60
10	·173	·176	40	·643	·839	70	·939	2·75
11	·191	·194	41	·656	·869	71	·945	2·90
12	·208	·212	42	·669	·900	72	·951	3·08
13	·225	·231	43	·682	·932	73	·956	3·27
14	·242	·249	44	·694	·965	74	·961	3·49
15	·259	·268	45	·707	1·000	75	·966	3·73
16	·275	·287	46	·719	1·03	76	·970	4·01
17	·292	·306	47	·731	1·07	77	·974	4·33
18	·309	·325	48	·743	1·11	78	·978	4·70
19	·325	·344	49	·755	1·15	79	·981	5·14
20	·342	·364	50	·766	1·19	80	·985	5·67
21	·358	·384	51	·777	1·23	81	·987	6·31
22	·374	·404	52	·788	1·28	82	·990	7·11
23	·391	·424	53	·798	1·33	83	·992	8·14
24	·407	·445	54	·809	1·37	84	·994	9·51
25	·422	·466	55	·819	1·43	85	·996	11·43
26	·438	·488	56	·829	1·48	86	·997	14·30
27	·454	·509	57	·838	1·54	87	·998	19·08
28	·469	·532	58	·848	1·60	88	·999	28·63
29	·485	·554	59	·857	1·66	89	·999	57·29
30	·500	·577	60	·866	1·73	90	1·000	Infinite.

(HUTTON's Tables.)

TABLE III.
FOR THE CONVERSION OF DEGREES OF THE CENTIGRADE THERMOMETER INTO THOSE OF FAHRENHEIT.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32·0	14	57·2	28	82·4
1	33·8	15	59·0	29	84·2
2	35·6	16	60·8	30	86·0
3	37·4	17	62·6	31	87·8
4	39·2	18	64·4	32	89·6
5	41·0	19	66·2	33	91·4
6	42·8	20	68·0	34	93·2
7	44·6	21	69·8	35	95·0
8	46·4	22	71·6	36	96·8
9	48·2	23	73·4	37	98·6
10	50·0	24	75·2	38	100·4
11	51·8	25	77·0	39	102·2
12	53·6	26	78·8	40	104·0
13	55·4	27	80·6	41	105·8

(MILLER's Chemistry.)

TABLE IV.
FRENCH WEIGHTS AND MEASURES.

Millimetre.	Inches.	Millimetre.	Inches.	Millimetre.	Inches.
1	0.039	45	1.771	125	4.941
2	0.078	50	1.968	130	5.118
3	0.118	55	2.165	135	5.315
4	0.157	60	2.362	140	5.512
5	0.197	65	2.559	145	5.708
6	0.236	70	2.756	150	5.906
7	0.275	75	2.953	155	6.103
8	0.315	80	3.149	160	6.299
9	0.354	85	3.346	165	6.496
10	0.394	90	3.543	170	6.693
15	0.590	95	3.740	175	6.890
20	0.787	100	3.937	180	7.087
25	0.984	105	4.134	185	7.284
30	1.181	110	4.331	190	7.480
35	1.378	115	4.528	195	7.677
40	1.575	120	4.744	200	7.874

1 inch = 25.4 millimetres.

	Inches.	Feet.	Yards.
1 Millimetre . . .	0.039	—	—
1 Centimetre . . .	0.393	—	—
1 Decimetre . . .	3.937	—	—
1 Metre	39.370	3.280	1.093
1 Kilometre . . .	39,370.790	3,280.899	1,093.633

Miles	1	2	3	4	5	6	7	8	9
Kilometres . . .	1.609	3.219	4.828	6.437	8.047	9.656	11.265	12.874	14.484

	Grains Troy.	Pounds Avoirdupois.
1 Milligramme	0.015	...
1 Centigramme	0.154	...
1 Decigramme	1.543	...
1 Gramme	15.432	...
1 Kilogramme	15,432.348	2.2046
2 " 	...	4.4092
3 " 	...	6.6138
4 " 	...	8.8184
5 " 	...	11.0230
6 " 	...	13.2276
7 " 	...	15.4322
8 " 	...	17.6368
9 " 	...	19.8414

7,000 grains Troy = 1 pound Avoirdupois.
1 Litre = 35.275 fluid ounces = 1.764 pints = 61.024 cubic inches.
1 cubic centimetre = .0610 cubic inches.

TABLE V.
MILES, CHAINS, YARDS, AND FEET.

Miles.	Chns.	Yds.	Feet.	Miles.	Chns.	Yds.	Feet.
.125 . . .	10	220	660	4.00 . . .	320	7040	21120
.25 . . .	20	440	1320	5.00 . . .	400	8800	26400
.50 . . .	40	880	2640	6.00 . . .	480	10560	31680
.75 . . .	60	1320	3960	7.00 . . .	560	12320	36960
1.00 . . .	80	1760	5280	8.00 . . .	640	14080	42240
2.00 . . .	160	3520	10560	9.00 . . .	720	15840	47520
3.00 . . .	240	5280	15840	10.00 . . .	800	17600	52800

Yds.		Chs.	Yds.	Yds.		Chs.	Yds.	Yds.		Chs.	Yds.
50	equal	2	6	650	equal	29	12	1250	equal	56	18
100	"	4	12	700	"	31	18	1300	"	59	2
150	"	6	18	750	"	34	2	1350	"	61	8
200	"	9	2	800	"	36	8	1400	"	63	14
250	"	11	8	850	"	38	14	1450	"	65	20
300	"	13	14	900	"	40	20	1500	"	68	4
350	"	15	20	950	"	43	4	1550	"	70	10
400	"	18	4	1000	"	45	10	1600	"	72	16
450	"	20	10	1050	"	47	16	1650	"	75	0
500	"	22	16	1100	"	50	0	1700	"	77	6
550	"	25	0	1150	"	52	6	1750	"	79	12
600	"	27	6	1200	"	54	12				

Chs.	Yds.	Chs.	Yds.	Chs.	Yds.	Chs.	Yds.
1 equal	22	21 equal	462	41 equal	902	61 equal	1342
2 "	44	22 "	484	42 "	924	62 "	1364
3 "	66	23 "	506	43 "	946	63 "	1386
4 "	88	24 "	528	44 "	968	64 "	1408
5 "	110	25 "	550	45 "	990	65 "	1430
6 "	132	26 "	572	46 "	1012	66 "	1452
7 "	154	27 "	594	47 "	1034	67 "	1474
8 "	176	28 "	616	48 "	1056	68 "	1496
9 "	198	29 "	638	49 "	1078	69 "	1518
10 "	220	30 "	660	50 "	1100	70 "	1540
11 "	242	31 "	682	51 "	1122	71 "	1562
12 "	264	32 "	704	52 "	1144	72 "	1584
13 "	286	33 "	726	53 "	1166	73 "	1606
14 "	308	34 "	748	54 "	1188	74 "	1628
15 "	330	35 "	770	55 "	1210	75 "	1650
16 "	352	36 "	792	56 "	1232	76 "	1672
17 "	374	37 "	814	57 "	1254	77 "	1694
18 "	396	38 "	836	58 "	1276	78 "	1716
19 "	418	39 "	858	59 "	1298	79 "	1738
20 "	440	40 "	880	60 "	1320	80 "	1760
$\frac{1}{4}$ mile.		$\frac{1}{4}$ mile.		$\frac{3}{4}$ mile.		1 mile.	

1 Statute Mile. = 1760 yards, or 5280 feet.
 1 Nautical Mile (knot or naut) = 2027 $\frac{1}{2}$ " " 6083 "
 1 Admiralty Knot = 2026 $\frac{1}{2}$ " " 6080 "
 1 Telegraph Knot. . . . = 2029 " " 6087 "

TABLE VI.
KNOTS AND STATUTE MILES.

Kts.	Miles.	Kts.	Miles.	Kts.	Miles.	Kts.	Miles.	Kts.	Miles.
1	1.1528	21	24.2096	41	47.2664	61	70.3232	81	93.3800
2	2.3057	2	25.3625	2	48.4193	2	71.4761	2	94.5329
3	3.4585	3	26.5153	3	49.5721	3	72.6289	3	95.6857
4	4.6114	4	27.6682	4	50.7250	4	73.7818	4	96.8386
5	5.7642	5	28.8210	5	51.8778	5	74.9346	5	97.9914
6	6.9170	6	29.9738	6	53.0306	6	76.0874	6	99.1442
7	8.0699	7	31.1267	7	54.1835	7	77.2403	7	100.2971
8	9.2127	8	32.2795	8	55.3363	8	78.3931	8	101.4499
9	10.3756	9	33.4324	9	56.4892	9	79.5460	9	102.6028
10	11.5284	30	34.5852	50	57.6420	70	80.6988	90	103.7556
1	12.6812	1	35.7380	1	58.7948	1	81.8516	1	104.9084
2	13.8341	2	36.8909	2	59.9477	2	83.0045	2	106.0613
3	14.9869	3	38.0437	3	61.1005	3	84.1573	3	107.2141
4	16.1398	4	39.1966	4	62.2534	4	85.3102	4	108.3670
5	17.2926	5	40.3494	5	63.4062	5	86.4630	5	109.5198
6	18.4454	6	41.5022	6	64.5590	6	87.6158	6	110.6726
7	19.5983	7	42.6551	7	65.7119	7	88.7687	7	111.8255
8	20.7511	8	43.8079	8	66.8647	8	89.9215	8	112.9783
9	21.9040	9	44.9608	9	68.0176	9	91.0744	9	114.1312
20	23.0568	40	46.1136	60	69.1704	80	92.2272	100	115.2840

STATUTE MILES AND KNOTS.

Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.	Stat. Miles.	Knots.
1	0.8674	21	18.2158	41	35.5643	61	52.9128	81	70.2612
2	1.7348	2	19.0833	2	36.4318	2	53.7802	2	71.1286
3	2.6023	3	19.9507	3	37.2992	3	54.6476	3	71.9960
4	3.4697	4	20.8181	4	38.1666	4	55.5150	4	72.8635
5	4.3371	5	21.6856	5	39.0340	5	56.3825	5	73.7309
6	5.2045	6	22.5530	6	39.9014	6	57.2499	6	74.5983
7	6.0719	7	23.4204	7	40.7689	7	58.1173	7	75.4657
8	6.9394	8	24.2878	8	41.6363	8	58.9847	8	76.3332
9	7.8068	9	25.1552	9	42.5037	9	59.8521	9	77.2006
10	8.6742	30	26.0227	50	43.3711	70	60.7196	90	78.0680
1	9.5416	1	26.8901	1	44.2386	1	61.5870	1	78.9354
2	10.4091	2	27.7575	2	45.1060	2	62.4544	2	79.8028
3	11.2765	3	28.6249	3	45.9734	3	63.3218	3	80.6703
4	12.1439	4	29.4924	4	46.8408	4	64.1892	4	81.5377
5	13.0113	5	30.3598	5	47.7082	5	65.0567	5	82.4051
6	13.8787	6	31.2272	6	48.5757	6	65.9241	6	83.2725
7	14.7462	7	32.0946	7	49.4431	7	66.7915	7	84.1400
8	15.6136	8	32.9620	8	50.3105	8	67.6590	8	85.0074
9	16.4810	9	33.8295	9	51.1779	9	68.5264	9	85.8748
20	17.3484	40	34.6969	60	52.0453	80	69.3938	100	86.7422

TABLE VII.
APPROXIMATE CUBICAL CONTENTS OF ROUND TELEGRAPH POLES.

Length.	MEAN DIAMETERS IN INCHES.															
	5	5½	6	6½	7	7½	8	8½	9	9½	10	11	12	13	14	15
	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
13 feet	2.45	2.70	2.96	3.24	3.53	3.83	4.14	4.47	4.81	5.16	5.52	5.89	6.28	6.68	7.09	7.51
20 "	2.72	3.00	3.29	3.60	3.92	4.25	4.60	4.97	5.34	5.73	6.13	6.55	6.98	7.42	7.88	8.35
22 "	2.99	3.30	3.62	3.96	4.31	4.68	5.07	5.46	5.87	6.30	6.74	7.20	7.67	8.16	8.66	9.18
24 "	3.27	3.60	3.95	4.32	4.71	5.11	5.53	5.96	6.41	6.88	7.36	7.86	8.37	8.90	9.45	10.02
26 "	3.54	3.90	4.28	4.68	5.11	5.53	5.99	6.46	6.94	7.45	7.97	8.51	9.07	9.65	10.24	10.85
28 "	3.81	4.20	4.62	5.04	5.49	5.96	6.45	6.95	7.48	8.02	8.58	9.17	9.77	10.39	11.03	11.69
30 "	4.09	4.50	4.94	5.40	5.88	6.38	6.91	7.45	8.01	8.60	9.20	9.82	10.47	11.13	11.82	12.52
32 "	4.36	4.81	5.27	5.77	6.28	6.81	7.37	7.96	8.55	9.17	9.81	10.48	11.17	11.87	12.61	13.36
34 "	4.63	5.11	5.60	6.13	6.67	7.24	7.83	8.44	9.08	9.74	10.43	11.13	11.86	12.62	13.39	14.19
36 "	4.90	5.41	5.93	6.49	7.06	7.66	8.29	8.94	9.62	10.32	11.04	11.79	12.56	13.36	14.18	15.03
38 "	5.18	5.71	6.26	6.85	7.46	8.09	8.75	9.44	10.15	10.89	11.65	12.44	13.26	14.10	14.97	15.86
40 "	5.45	6.01	6.59	7.21	7.85	8.52	9.21	9.94	10.69	11.40	12.27	13.10	13.96	14.84	15.76	16.70
42 "	5.72	6.31	6.92	7.57	8.24	8.94	9.67	10.43	11.22	12.03	12.88	13.75	14.65	15.59	16.54	17.53
44 "	6.00	6.61	7.25	7.93	8.64	9.38	10.15	10.93	11.76	12.61	13.50	14.40	15.36	16.34	17.34	18.37
46 "	6.26	6.90	7.57	8.28	9.01	9.78	10.58	11.59	12.27	13.16	14.09	15.04	16.03	17.05	18.13	19.18
48 "	6.54	7.21	7.91	8.65	9.42	10.22	11.06	11.92	12.82	13.76	14.72	15.72	16.75	17.81	18.91	20.04
50 "	6.81	7.51	8.25	9.01	9.81	10.65	11.52	12.42	13.35	14.33	15.33	16.37	17.44	18.54	19.70	20.87

TABLE VIII.

SHOWING THE STRAIN CORRESPONDING TO THE SAG OR DIP OF A
WIRE SUSPENDED AT BOTH ENDS.

Sag in Inches.	No. 8 Wire (ordinary), 88 yards span.	No. 8 Wire (ordinary), 110 yards' span.	No. 11 Wire (homogeneous), 110 yards' span.	No. 11 Wire (ordinary), 110 yards' span.
	lbs.	lbs.	lbs.	lbs.
24	313	429	266	224
23	326	448	280	235
22	340	467	291	246
21	359	486	302	257
20	377	504	313	268
19	397	532	324	280
18	418	560	336	294
17	448	588	355	308
16	477	616	374	322
15	510	...	392	336
14	543	...	420	355
13	588	...	448	374
12	624	...	476	392
11	690	...	504	420
10	756	...	...	448
9	841	...	...	476
8	926	...	...	504
7	1,018	...	...	...

The larger figures are the results of actual observation, the smaller are filled in from calculation. The differences from the theoretical values are caused by the stiffness of the wire, which prevents it taking the true curve. The table may be useful as showing that relation between sag and strain which is likely to be met with in practice.

TABLE IX.

IRON AND COPPER WIRE.

IRON WIRE.

Birmingham Wire Gauge.	Diameter.		Area of Section.	Weight of 100 yards.	Weight of 1 mile.	Length of 1 cwt.	Breaking Strain.	
							Hard Wire.	Soft Wire.
	Inches.	Milli-metres.	Sq. in.	Lbs.	Lbs.	Yards.	Lbs.	Lbs.
00	0.363	9.21	0.103	102.00	1794	110	8600	6000
0	0.331	8.40	0.086	84.72	1490	132	7100	4750
1	0.300	7.61	0.071	68.75	1210	162	6000	4000
2	0.280	7.11	0.062	59.90	1054	187	4850	3400
3	0.260	6.60	0.053	51.65	909	215	4000	2900
4	0.240	6.10	0.045	44.00	775	255	3400	2500
5	0.220	5.59	0.038	37.00	651	303	2950	2200
6	0.200	5.08	0.031	30.56	538	361	2500	1800
7	0.185	4.69	0.0265	26.15	461	428	2200	1520
8	0.170	4.31	0.023	22.10	389	509	1750	1200
9	0.155	3.93	0.0195	18.36	323	609	1500	950
10	0.140	3.55	0.016	14.97	264	747	1200	820
11	0.125	3.17	0.0125	11.95	211	939	820	650
12	0.110	2.79	0.010	9.21	163	1244	710	510
13	0.095	2.41	0.0071	7.05	124	1589	640	400
14	0.085	2.15	0.0057	5.51	97	2031	510	350
15	0.075	1.92	0.0044	4.29	76	2608	410	300
16	0.065	1.65	0.0033	3.22	57	3473	350	200
17	0.057	1.44	0.0026	2.48	44	4515	280	160
18	0.050	1.27	0.0020	1.91	34	5600	200	115
19	0.045	1.14	0.0016	1.55	27	7246	150	85
20	0.040	1.01	0.0013	1.22	21	9198	110	65
21	0.035	0.88	0.0010	0.94	17	11980	85	50
22	0.030	0.76	0.0007	0.69	12	16300	65	40

The above table has been supplied by Messrs. Johnson and Nephew, of Manchester; the soft wire is that manufactured by them expressly for telegraphic purposes.

Birmingham Wire Gauge.—The diameters of the several gauges must be considered approximate only. There is no authorized standard, and the sizes of different makers vary considerably.

TABLE IX.—(continued).

COPPER WIRE.

(Hall.)

Birmingham Wire Gauge (Approximate).	Diameter.		Number of yards in 1 pound.	Weight in lbs. of 1 mile (1760 yards).	Resistance of 1 mile of pure Copper at 82° Fahr.	Approximate weight of silk required to cover a pound of wire singly.
	Inches.	Milli- metres.				Oz.
4½	·2302	5·847	2·095	840·09	1·00	
5	·226	5·740	2·175	809·20	1·038	
6	·198	5·029	2·834	621·00	1·352	
7	·183	4·648	3·317	530·59	1·583	
8	·175	4·445	3·628	485·10	1·731	
9	·160	4·064	3·350	404·60	2·068	
10	·136	3·454	6·007	292·99	2·867	
11	·128	3·251	6·781	259·55	3·237	
12	·107	2·717	9·705	181·85	4·623	
13	·10	2·54	11·11	158·41	5·300	
...	·092	2·336	13·125	134·40	6·266	
14½	·08	2·032	17·36	101·39	8·288	
15½	·07	1·778	22·67	77·63	10·82	
16	·065	1·651	26·29	66·96	12·25	
...	·0625	1·587	28·472	61·81	13·59	
...	·06	1·521	30·864	57·02	14·73	
17	·058	1·473	33·03	53·29	15·76	
...	·056	1·422	35·432	49·67	16·91	
...	·054	1·371	38·104	46·19	18·18	
...	·052	1·32	41·091	42·83	19·61	
18	·05	1·274	44·444	39·60	21·21	
...	·048	1·219	48·225	36·50	23·02	
...	·046	1·168	52·51	33·52	25·06	
19	·044	1·117	57·39	30·67	27·39	
...	·042	1·066	62·98	27·94	30·06	
20	·04	1·016	69·444	25·34	33·14	
...	·038	·965	77·16	22·81	36·72	
21	·036	·914	85·766	20·52	40·92	
...	·034	·864	95·29	18·47	45·48	
...	·032	·813	108·5	16·22	51·79	
22	·03	·762	123·46	14·26	58·93	
...	·028	·711	141·72	12·42	67·65	
23½	·026	·660	164·36	10·71	78·46	
24½	·024	·609	192·9	9·12	92·08	
25	·022	·558	229·56	7·61	109·58	1
26	·02	·508	277·78	6·33	132·59	

TABLE IX.—(continued).

COPPER WIRE

Birmingham Wire Gauge (Approximate).	Diameter.		Number of yards in 1 pound.	Weight in lbs. of 1 mile (1760 yards).	Resistance of 1 mile of pure Copper at 82° Fahr.	Approximate weight of Silk required to cover a pound of Wire single
	Inches.	Milli- metres.				oz.
27	·018	·457	842·94	5·13	163·69	1
28	·016	·406	434·03	4·05	207·17	
30	·014	·355	569·51	3·09	270·58	
31	·012	·305	771·60	2·28	368·30	1½
32	·01	·254	1111·11	1·58	530·35	
34	·0095	·241	1231·10	1·43	587·64	
...	·009	·228	1371·7	1·28	654·75	2
35	·0085	·216	1537·8	1·14	734·05	
36	·008	·203	1736·1	1·01	828·67	
...	·0075	·190	1975·3	0·8910	942·84	2½
...	·007	·177	2267·6	0·7761	1082·4	
37	·0065	·165	2629·9	0·6692	1225·3	
38	·006	·152	3086·4	0·5702	1473·1	3
...	·0055	·139	3673·1	0·4791	1753·2	
...	·005	·127	4444·4	0·3960	2121·4	
39	·0045	·114	5487·0	0·3207	2619·0	4
40	·004	·106	6944·4	0·2534	3314·7	
..	·0035	·088	9070·3	0·1945	4329·4	
41	·003	·076	12346·0	0·1425	5892·7	5
...	·0025	·063	17777·0	0·099	8485·6	

To find the percentage of Conductivity in a sample of wire, pure copper being taken as = 100 :—

Divide the resistance of 1 mile of pure copper wire of the same size (column 6), by the actual resistance of 1 mile of the wire tested (reduced to 82° Fahr.), and multiply by 100.

TABLE X.
AMERICAN WIRE GAUGE.

No. of Gauge.	Size of each No.	WEIGHT OF WIRE, PER 1000 LINEAL FEET.			
		Wrought Iron.	Steel.	Copper.	Brass.
	Inch.	Lbs.	Lbs.	Lbs.	Lbs.
0000	·46000	560·74	566·08	640·51	605·18
000	·40964	444·68	448·88	507·95	479·91
00	·36480	352·66	355·99	402·83	380·67
0	·32436	279·67	282·30	319·45	301·32
1	·28930	221·79	223·89	253·34	239·35
2	·25763	175·89	177·55	200·91	189·82
3	·22942	139·48	140·80	159·32	150·52
4	·20431	110·62	111·66	126·35	119·38
5	·18194	87·720	88·548	100·20	94·666
6	·16202	69·565	70·221	79·462	75·075
7	·14428	55·165	55·685	63·013	59·545
8	·12849	43·751	44·164	49·976	47·219
9	·11443	34·699	35·026	39·636	37·437
10	·10189	27·612	27·772	31·426	29·687
11	·090742	21·820	22·026	24·924	23·549
12	·080808	17·304	17·468	19·766	18·676
13	·071961	13·722	13·851	15·674	14·809
14	·064084	10·886	10·989	12·435	11·746
15	·057068	8·631	8·712	9·859	9·315
16	·050820	6·845	6·909	7·819	7·587
17	·045257	5·427	5·478	6·199	5·857
18	·040303	4·304	4·344	4·916	4·645
19	·035890	3·413	3·445	3·899	3·684
20	·031961	2·708	2·734	3·094	2·920
21	·028462	2·147	2·167	2·452	2·317
22	·025347	1·703	1·719	1·945	1·838
23	·022571	1·360	1·363	1·542	1·457
24	·020100	1·071	1·081	1·223	1·155
25	·017900	0·8491	0·8571	·9699	0·9163
26	·015940	0·6734	0·6797	·7692	0·7267
27	·014195	0·5340	0·5391	·6099	0·5763
28	·012641	0·4235	0·4275	·4837	0·4570
29	·011257	0·3358	0·3389	·3835	0·3624
30	·010025	0·2663	0·2688	·3042	0·2874
31	·008928	0·2113	0·2132	·2413	0·2280
32	·007950	0·1675	0·1691	·1913	·1803
33	·007080	0·1328	0·1341	·1517	·1434
34	·006304	0·1053	0·1063	·1204	·1137
35	·005614	·08366	·08445	·0956	·09015
36	·005000	·06625	·06687	·0757	·0716
37	·004453	·05255	·05304	·06003	·05671
38	·003965	·04166	·04205	·04758	·04496
39	·003531	·03305	·03336	·03775	·03566
40	·003144	·02620	·02644	·02992	·02827
SPECIFIC GRAVITY .		7·7747	7·847	8·880	8·386
WEIGHT PER CUBIC					
FOOT		485·874	90·45	554·988	524·16

(From NYSTROM'S Pocket-book.)

TABLE XI.

RESISTANCES IN OHMS OF METALS AND ALLOYS AT 0° CENTIGRADE
(32° FAHRENHEIT).

METALS AND ALLOYS.	Relative Resistances, Silver = 1.	Resistance of a wire one foot long, weighing one grain.	Resistance of a wire one foot long, 1-1000th inch in diameter.	Approximate percentage of variation in resistance per degree of temperature at 20° C.
Silver, annealed	1.00	0.2214	9.936	0.377
„ hard drawn	0.92	0.2421	9.151	...
Copper, annealed	0.98	0.2064	9.788	0.388
„ hard drawn	1.00	0.2106	9.940	...
Gold, annealed	1.26	0.5849	12.52	0.365
„ hard drawn	1.23	0.5950	12.74	...
Brass	4.50	...	...	...
Aluminium, annealed . .	1.78	0.1085	17.72	...
Platinum, annealed . . .	5.54	3.536	55.09	...
Iron, annealed	5.95	1.2425	59.10	...
Tin, pressed	8.09	1.317	80.36	0.365
Lead, pressed	12.02	3.286	119.39	0.387
German Silver, hard or annealed	12.81	2.652	127.82	0.044
Platinum Silver alloy, hard or annealed (two parts Platinum, one part Silver)	14.93	4.243	148.35	0.031
Mercury, liquid	60.38	18.740	600.0	0.072

Let it be required to know the resistance at 0° of a conductor of pure *hard* copper, weighing 400 lbs. per knot. This is equivalent to 460 grains per foot. The resistance of a wire weighing one grain per foot is 0.2106; therefore, the resistance of a foot of wire weighing 460 grains will be $\frac{0.2106}{460}$, but the resistance of one knot will be 6,087 times that of one foot, hence the resistance required will be $\frac{6087 \times 0.2106}{460} = 2.79$ units. If the diameter of the wire be given, instead of its weight per knot, the constant for English measures would be taken from the fourth column of the table. Thus the resistance at 0° of a knot of pure hard drawn copper wire 0.1 in. diameter would be $\frac{6087 \times 9.94}{100^2} = 6.05$.

(JENKIN.)

TABLE XII.

RESISTANCE IN OHMS OF WIRES ONE FOOT LONG WEIGHING ONE GRAIN, AT VARIOUS TEMPERATURES.

(Jenkin.)

Temperature.		Soft Copper.	Hard Copper.	German Silver.	Platinum Silver.
Fahrenheit.	Centigrade.				
32	0	0.2064	0.2106	2.652	4.24
41	5	0.2102	0.2147	2.657	4.25
50	10	0.2144	0.2188	2.661	4.25
51.8	11	0.2153	0.2197	...	...
53.6	12	0.2161	0.2205	...	...
55.4	13	0.2170	0.2214	...	...
57.2	14	0.2178	0.2222	...	...
59.0	15	0.2186	0.2231	2.666	4.26
60.8	16	0.2194	0.2239	...	...
62.6	17	0.2203	0.2248	...	...
64.4	18	0.2211	0.2256	...	...
66.2	19	0.2220	0.2265	...	...
68.0	20	0.2228	0.2272	2.670	4.27
69.8	21	0.2237	0.2283	...	...
71.6	22	0.2242	0.2288	...	...
73.4	23	0.2253	0.2299	...	...
75.2	24	0.2262	0.2308	...	...
77.0	25	0.2271	0.2317	2.675	4.27
78.8	26	0.2279	0.2325	...	...
80.6	27	0.2287	0.2334	...	...
82.4	28	0.2296	0.2343	...	...
84.2	29	0.2305	0.2352	...	...
86.0	30	0.2313	0.2360	2.680	4.28
87.8	31	0.2322	0.2369	...	...
89.6	32	0.2328	0.2375	...	...
91.4	33	0.2340	0.2388	...	...
93.2	34	0.2348	0.2396	...	...
95.0	35	0.2357	0.2405	2.684	4.28
96.8	36	0.2365	0.2413	...	...
98.6	37	0.2376	0.2424	...	...
100.4	38	0.2383	0.2432	...	...
102.2	39	0.2391	0.2440	...	...
104.0	40	0.2400	0.2449	2.689	4.29

At zero Cent.—

1 foot-grain Platinum, annealed = 3.536 ohms.

1 " Silver, hard = 0.2421 "

By weight 1 Platinum = 14.6 Silver.

1 foot .001 inch in diameter Platinum = 55.09 "

1 " " Silver = 9.151 "

By volume 1 Platinum = 6.009 Silver.

The resistance of German Silver varies with its composition. A sample tested by Mr. Becker showed a resistance of 3.644 ohms at 58° Fahr. for a foot-grain.

TABLE XIII.
CO-EFFICIENTS FOR THE REDUCTION OF THE RESISTANCE OF COPPER
WIRES OF VARYING CONDUCTIVITY TO ANY OTHER TEMPERATURE.

CO-EFFICIENTS FOR THE REDUCTION TO A HIGHER TEMPERATURE.

(G. E. P.)

Difference of Tem- perature. Degrees Fahr.	PURE COPPER.		96 PER CENT.		94 PER CENT.		92 PER CENT.	
	Co- efficient.	Log.	Co- efficient.	Log.	Co- efficient.	Log.	Co- efficient.	Log.
0	1.00000	0.0000000	1.0000	0.0000000	1.00000	0.00000000	1.0000	0.0000000
1	1.00206	.0008950	1.0020	.0008592	1.00194	.0008418	1.00190	.0008234
2	1.00413	.0017900	1.0040	.0017184	1.0039	.0016826	1.0038	.0016468
3	1.00620	.002685	1.00595	.0025776	1.0058	.0025289	1.0057	.0024702
4	1.00828	.003580	1.00795	.0034368	1.0078	.0033652	1.0076	.0032986
5	1.01036	.004475	1.00995	.0042960	1.0097	.0042065	1.0095	.0041170
6	1.01244	.005370	1.01195	.0051552	1.0117	.0050478	1.01145	.0049404
7	1.01453	.006265	1.01395	.0060144	1.01355	.0058891	1.01365	.0057638
8	1.01662	.007160	1.01595	.0068736	1.0156	.0067304	1.0153	.0065872
9	1.01872	.008055	1.0180	.0077328	1.0176	.0075717	1.0172	.0074106
10	1.02082	.008950	1.0199	.0085920	1.0196	.0084130	1.01915	.0082310
11	1.02293	.009845	1.0220	.0094512	1.0215	.0092548	1.0211	.0090574
12	1.02504	.010740	1.0240	.0103104	1.0235	.0100956	1.0230	.0098808
13	1.02715	.011635	1.02605	.0111606	1.0255	.0109869	1.02495	.0107704
14	1.02927	.012530	1.0281	.0120288	1.0276	.0117782	1.0269	.01155276
15	1.03139	.013425	1.0301	.0128880	1.0295	.0126195	1.02885	.0123510
16	1.03352	.014320	1.03215	.0137472	1.0315	.0134608	1.030	.0131744
17	1.03565	.015215	1.0342	.0146064	1.0335	.0143021	1.03275	.0139978
18	1.03779	.016110	1.03625	.0154656	1.0355	.0151434	1.0347	.0148212
19	1.03993	.017005	1.0383	.0163248	1.0375	.0159847	1.0367	.0156446
20	1.04208	.017900	1.04035	.0171840	1.0395	.0168260	1.03865	.0164680
21	1.04423	.018795	1.0424	.0180432	1.0415	.0176673	1.0406	.0172914
22	1.04638	.019690	1.0448	.0189024	1.0435	.0185086	1.0426	.0181148
23	1.04854	.020585	1.04655	.0197616	1.0455	.0193499	1.0446	.0189382
24	1.05070	.021480	1.0486	.0206208	1.0476	.0201912	1.04655	.0197616
25	1.05287	.022375	1.0507	.0214800	1.0496	.0210325	1.04855	.0205850
26	1.05504	.023270	1.0528	.0223392	1.05165	.0218738	1.0505	.0214084
27	1.05722	.024165	1.0549	.0231984	1.0537	.0227151	1.0525	.0222318
28	1.05940	.025060	1.05695	.0240576	1.0557	.0235564	1.0545	.0230552
29	1.06158	.025955	1.05905	.0249168	1.0578	.0243977	1.0565	.0238786
30	1.06377	.026850	1.06115	.0257760	1.0598	.0252390	1.0585	.0247020

To reduce the resistance of a Copper Wire of a specified conductivity from the observed temperature to a higher.—Under the column corresponding to the specified conductivity, and opposite the number of degrees answering to the difference between the observed and the required temperature, will be found the co-efficient; multiply the observed resistance by this co-efficient, and the product is the resistance required.

For reducing to a lower temperature proceed in the same manner, but obtain the co-efficient from the second table.

TABLE XIII.—(continued).

CO-EFFICIENTS FOR THE REDUCTION TO A LOWER TEMPERATURE.

(G. E. P.)

Difference of Tem- perature. Degrees Fahr.	PURE COPPER.		96 PER CENT.		94 PER CENT.		92 PER CENT.	
	Co- efficient.	Log.	Co- efficient.	Log.	Co- efficient.	Log.	Co- efficient.	Log.
0	1.00000	0.0000000	1.00000	0.0000000	1.00000	0.0000000	1.00000	0.0000000
1	0.99794	1.9991050	0.99802	1.9991408	0.998065	1.9991537	0.998105	1.9991766
2	0.99588	.9982100	0.99605	.9982816	0.99613	.9983174	0.996215	.9983532
3	0.99383	.9973150	0.99408	.9974224	0.994205	.9974761	0.99433	.9975298
4	0.99179	.9964200	0.99212	.9965432	0.99228	.9966348	0.992445	.9967064
5	0.98975	.9955250	0.99016	.9957040	0.99036	.9957935	0.990565	.9958830
6	0.98771	.9946300	0.98820	.9948448	0.988445	.9949522	0.98869	.9950596
7	0.98567	.9937350	0.98625	.9939856	0.98653	.9941109	0.98682	.9942362
8	0.98365	.9928400	0.98430	.9931264	0.98462	.9932696	0.98494	.9934128
9	0.98162	.9919450	0.98235	.9922672	0.98272	.9924283	0.98308	.9925894
10	0.97960	.9910500	0.98041	.9914080	0.980815	.9915870	0.98122	.9917660
11	0.97758	.9901550	0.97847	.9905488	0.978915	.9907457	0.97936	.9909426
12	0.97557	.9892600	0.97654	.9896896	0.97702	.9899044	0.97751	.9901192
13	0.97356	.9883650	0.97461	.9888304	0.97513	.9890691	0.97565	.9892958
14	0.97156	.9874700	0.97268	.9879712	0.973245	.9882218	0.973805	.9884724
15	0.96956	.9865750	0.97076	.9871120	0.97136	.9873805	0.97196	.9876490
16	0.96756	.9856800	0.96884	.9862528	0.96948	.9865392	0.97012	.9868256
17	0.96557	.9847850	0.96693	.9853936	0.967605	.9856979	0.96828	.9860022
18	0.96358	.9838900	0.96502	.9845344	0.96573	.9848566	0.96645	.9851788
19	0.96160	.9829950	0.96311	.9836752	0.96386	.9840153	0.96462	.9843554
20	0.95962	.9821000	0.961205	.9828160	0.96200	.9831740	0.96279	.9835320
21	0.95764	.9812050	0.959305	.9819568	0.96014	.9823327	0.96097	.9827086
22	0.95567	.9803100	0.95741	.9810976	0.95828	.9814914	0.95915	.9818852
23	0.95370	.9794150	0.95552	.9802384	0.95642	.9806501	0.95783	.9810618
24	0.95174	.9785200	0.95363	.9793792	0.95457	.9798088	0.95552	.9802384
25	0.94978	.9776250	0.95174	.9785200	0.952725	.9789675	0.95371	.9794150
26	0.94783	.9767300	0.94986	.9776608	0.95088	.9781262	0.95190	.9785916
27	0.94587	.9758350	0.947985	.9768016	0.94904	.9772849	0.95010	.9777682
28	0.94393	.9749400	0.94611	.9759424	0.947205	.9764436	0.94830	.9769448
29	0.94198	.9740450	0.94424	.9750832	0.94537	.9756023	0.94650	.9761214
30	0.94004	.9731500	0.942375	.9742240	0.94354	.9747610	0.94471	.9752980

To reduce the resistance of a Copper Wire of a specified conductivity from the observed temperature to a higher.—Under the column corresponding to the specified conductivity and opposite the number of degrees answering to the difference between the observed and the required temperature, will be found the co-efficient; multiply the observed resistance by this co-efficient, and the product is the resistance required.

For reducing to a lower temperature proceed in the same manner, but obtain the co-efficient from the second table.

TABLE XIV.

RESISTANCE OF A KNOT-POUND OF PURE COPPER AT VARYING TEMPERATURES.

Degrees.	Resistance.	Degrees.	Resistance.
75° Fahr.	1192·38 Ohm.	53° Fahr.	1139·48 Ohm.
74	1189·87	52	1137·18
73	1187·42	51	1134·79
72	1184·98	50	1132·45
71	1182·54	49	1130·12
70	1180·10	48	1127·80
69	1177·67	47	1125·48
68	1175·25	46	1123·16
67	1172·83	45	1120·85
66	1170·42	44	1118·54
65	1168·01	43	1116·24
64	1165·60	42	1113·94
63	1163·20	41	1111·64
62	1160·81	40	1109·35
61	1158·42	39	1107·07
60	1156·03	38	1104·79
59	1153·65	37	1102·52
58	1151·28	36	1100·25
57	1148·91	35	1097·98
56	1146·54	34	1095·72
55	1144·18	33	1093·47
54	1141·83	32	1091·22

TABLE XV.

INFLUENCE OF TEMPERATURE ON INSULATING MATERIAL.

Table of Co-efficients for the reduction of the observed insulation resistance of a core at any temperature to that at 75° Fahr.

(G. E. P.)

Temp. Fahr.	Ordinary Percha.		Willoughby Smith's Improved Percha.		Hooper's Insulator.		Temp. Fahr.
	Co-efficient.	Logarithm.	Co-efficient.	Logarithm.	Co-efficient.	Logarithm.	
32°	23·622	1·3733167	27·913	1·4458065	3·016	0·4794313	32°
33	21·947	·8413752	25·834	·4121917	2·940	·4683473	33
34	20·391	·3094385	23·910	·3785796	2·865	·4571246	34
35	18·945	·2774946	22·128	·8449422	2·796	·4465372	35
36	17·602	·2455620	20·480	·3113300	2·722	·4348881	36
37	16·354	·2136240	18·954	·2777009	2·653	·4237372	37
38	15·195	·1817007	17·542	·2440791	2·586	·4126285	38
39	14·117	·1497424	16·235	·2104523	2·520	·4014005	39
40	13·116	·1178014	15·025	·1768145	2·456	·3902284	40
41	12·186	·0858612	13·906	·1432022	2·394	·3791241	41
42	11·322	·0539232	12·870	·1095785	2·333	·3679147	42
43	10·520	·0220157	11·911	·0759482	2·274	·3567905	43
44	9·774	0·9900723	11·024	·0423392	2·216	·3455698	44
45	9·081	·9581837	10·203	·0087279	2·160	·3344533	45
46	8·437	·9261880	9·442	0·9750640	2·105	·3232521	46
47	7·839	·8942607	8·739	·9414617	2·052	·3121774	47
48	7·283	·8623103	8·088	·9078411	2·000	·3010300	48
49	6·767	·8303962	7·485	·8741918	1·949	·2898118	49
50	6·287	·7984435	6·928	·8406079	1·900	·2787536	50
51	5·841	·7664372	6·412	·8069935	1·852	·2676410	51
52	5·427	·7345598	5·934	·7733475	1·805	·2564772	52
53	5·042	·7026028	5·492	·7397305	1·759	·2452658	53
54	4·685	·6707096	5·083	·7061201	1·715	·2342641	54
55	4·353	·6387887	4·704	·6724673	1·671	·2229764	55
56	4·044	·6068111	4·354	·6388884	1·629	·2119211	56
57	3·757	·5748412	4·029	·6051973	1·587	·2005769	57
58	3·491	·5429498	3·729	·5715924	1·547	·1894903	58
59	3·244	·5110808	3·451	·5379450	1·508	·1784013	59
60	3·013	·4789991	3·194	·5043349	1·470	·1673178	60
61	2·800	·4471580	2·956	·4707044	1·433	·1562462	61
62	2·601	·4151404	2·736	·4371161	1·396	·1448854	62
63	2·417	·3832767	2·532	·4034637	1·361	·1333581	63
64	2·245	·3512163	2·343	·3697723	1·326	·1225435	64
65	2·086	·3193143	2·169	·3362596	1·293	·1115935	65
66	1·938	·2873538	2·007	·3025474	1·260	·1003705	66
67	1·801	·2555137	1·858	·2690457	1·228	·0891984	67
68	1·673	·2234959	1·719	·2352759	1·197	·0780942	68
69	1·555	·1917304	1·591	·2016702	1·167	·0670709	69
70	1·444	·1595672	1·473	·1682027	1·137	·0557605	70
71	1·342	·1277525	1·363	·1344959	1·108	·0445398	71
72	1·247	·0958665	1·261	·1007151	1·080	·0334238	72
73	1·158	·0637086	1·167	·0670709	1·053	·0224234	73
74	1·076	·0318123	1·080	·0334238	1·026	·0111474	74
75	1·000	·0000000	1·000	·0000000	1·000	·0000000	75
76	·9418	1·9739587	·9375	1·9719713	·9746	1·888264	76
77	·8870	·9479236	·8789	·9439395	·9500	·9777236	77
78	·8354	·9218945	·8240	·9159272	·9259	·9665641	78
79	·7867	·8958092	·7725	·8878985	·9034	·9558801	79

TABLE XV.—(continued).
INFLUENCE OF TEMPERATURE ON INSULATING MATERIAL.

Temp. Fahr.	Ordinary Percha.		Willoughby Smith's Improved Percha.		Hooper's Insulator.		Temp. Fahr.
	Co-efficient.	Logarithm.	Co-efficient	Logarithm.	Co-efficient.	Logarithm.	
80°	·7410	·8698182	·7242	·8598585	·8795	·9442358	80°
81	·6978	·8437310	·6789	·8318058	·8572	·9330822	81
82	·6572	·8176976	·6365	·8037984	·8355	·9219465	82
83	·6190	·7916906	·5967	·7757560	·8144	·9108378	83
84	·5829	·7655941	·5594	·7477225	·7937	·8996564	84
85	·5490	·7395723	·5245	·7197455	·7786	·8885165	85
86	·5171	·7185745	·4917	·6917002	·7540	·8773713	86
87	·4870	·6875290	·4609	·6636067	·7349	·8662282	87
88	·4586	·6614341	·4321	·6355843	·7162	·8550343	88
89	·4319	·6353832	·4051	·6075622	·6981	·8439176	89
90	·4068	·6093809	·3798	·5795550	·6804	·8327643	90
91	·3831	·5833122	·3561	·5515720	·6631	·8215790	91
92	·3608	·5572665	·3338	·5234863	·6463	·8104342	92
93	·3398	·5312234	·3130	·4955443	·6299	·7992716	93
94	·3200	·5051500	·2934	·4674601	·6140	·7881684	94
95	·3014	·4791432	·2751	·4394906	·5984	·7769916	95
96	·2839	·4531654	·2579	·4114513	·5832	·7658175	96
97	·2674	·4271614	·2417	·3832767	·5541	·7435882	97
98	·2518	·4010557	·2266	·3552599	·5400	·7323938	98
99	·2371	·3749316	·2125	·3273589	·5263	·7212334	99
100	·2233	·3488887	·1992	·2992893	·5130	·7101174	100

To find the resistance at a given temperature from an observed resistance at another temperature :—

As the co-efficient of the observed temperature is to the co-efficient of the required temperature, so is the observed resistance to the resistance required.

Where the resistance required is at 75° Fahr., it will be sufficient to divide the observed resistance by the co-efficient corresponding to the observed temperature in the table.

The resistances of percha are as given by Mr. Willoughby Smith ; those of Hooper's Insulator are as given by Mr. Warren, in Clark and Sabine's "Electrical Tables."

The improvement effected by Mr. Willoughby Smith has reduced the electrostatic capacity about twenty per cent., without in any way injuring the mechanical or chemical properties.

TABLE XVI.

RESISTANCE (COMPARATIVE) OF ORDINARY AND WILLOUGHBY SMITH'S GUTTA-PERCHA, AND HOOPER'S MATERIAL, AT DIFFERENT TEMPERATURES, SHOWING THE DECREASE OF RESISTANCE DUE TO THE INCREASE OF TEMPERATURE.

(G. E. P.)

Temperature.	Ordinary Gutta-Percha.	Willoughby Smith's Gutta-Percha.	Hooper's Material.
32°	100·00	100·00	100·00
35	80·20	79·27	92·71
40	55·52	58·83	81·43
45	38·44	36·55	71·62
50	26·62	24·82	63·00
55	18·43	16·85	55·40
60	12·76	11·44	48·74
65	8·83	7·77	42·87
70	6·11	5·28	37·70
75	4·23	3·58	33·16
80	3·14	2·59	29·16
85	2·32	1·88	27·67
90	1·72	1·36	23·62
95	1·28	0·98	19·84
100	·94	0·71	17·01

The data for Gutta-percha are from Mr. Willoughby Smith's tables; those for Hooper's Material from Mr. Warren's table, as given in Clark and Sabine.

TABLE XVII.
WEIGHTS OF COPPER AND GUTTA-PERCHA.
SILVERTOWN TABLE. PER NAUT, 2,029 YARDS.

Gauge.	Diameter.	Copper.	Gutta-Percha (solid).
No. 1	·310	Lbs. 1778·4	Lbs. 192·7
2	·280	1434·7	155·9
3	·260	1246·5	135·4
4	·240	1058·4	115·0
5	·220	898·7	97·0
6	·200	729·1	79·2
7	·187	635·0	69·0
8	·166	493·9	53·6
9	·158	446·8	48·5
10	·137	329·2	35·7
11	·125	282·2	30·6
12	·109	211·6	23·0
13	·095	164·6	17·8
14	·083	117·6	12·7
15	·072	94·0	10·2
16	·065	70·5	7·6
17	·056	47·0	5·1
18	·049	42·8	4·6
19	·042	30·5	3·3
20	·035	21·1	2·3

This table has been furnished by the Silvertown Gutta-Percha Works. It will be observed that the diameters of the gauges vary from those given in Table IX., and that the specific gravity of the copper differs also.

To find the weight of the percha of a core of given diameter, deduct the weight of a cylinder of percha equal in diameter to the conductor from the tabular weight of solid gutta-percha.

GUTTA-PERCHA COMPANY'S TABLE.

Gauge.	Diameter.	Weight per Stat. Mile. Gutta-Percha (solid).	Weight per Naut. Mile. Gutta Percha (solid).
		Lbs.	Lbs.
00	·126	28	32
0	·143	36	41
8	·161	46	53
7	·171	52	59
6	·194	66	77
5	·214	81	93
4	·221	86	99
3	·247	108	124
2	·276	134	155
1	·289	147	170
0	·340	204	235
00	·380	255	294
000	·425	319	368
0000	·454	364	420
1/4-inch	·500	442	509

This table has been furnished by Mr. Chatterton, of the Gutta-Percha Company, Wharf Road.

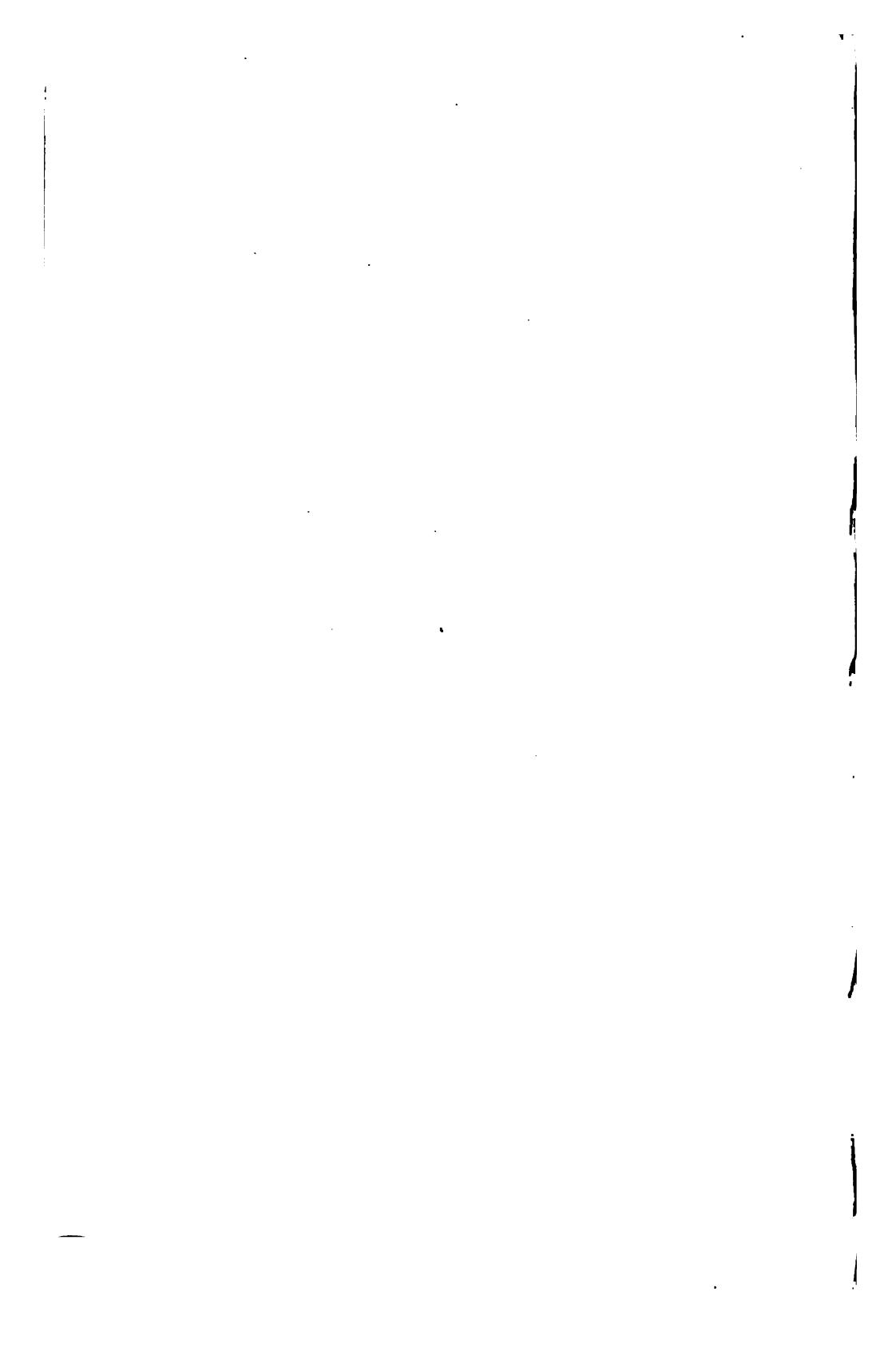
The weight and diameter of No. 7 gauge, the size used for underground wires in towns, are, approximately—

Outside diameter 171 inch.
Weight of Copper per statute mile 39 lbs.
" Percha " 46 "

MECHANICAL AND ELECTRICAL DATA OF VARIOUS RECENT SUBMARINE TELEGRAPH CABLES.

[illegible]

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